PERFORMANCE OF THE 100 MEV INJECTOR LINAC FOR THE ELECTRON STORAGE RING AT KYOTO UNIVERSITY

T.Shirai, T.Sugimura, Y.Iwashita, S.Kakigi, H.Fujita,
H.Tonguu, A.Noda and M.Inoue
Nuclear Science Research Facility, Institute for Chemical Research, Kyoto University
Gokanosho, Uji, Kyoto 611, Japan

Abstract

An electron linear accelerator has been constructed as an injector of a 300 MeV electron storage ring (Kaken Storage Ring, KSR) at Institute for Chemical Research, Kyoto University. The output beam energy of the linac is 100 MeV and the designed beam current is 100 mA at the 1 μsec long pulse mode.

The transverse and longitudinal emittance are measured to evaluate the beam quality for the beam injection into the KSR. They are observed by the profile monitors combined with quadrupole magnets or an RF accelerator. The results are that the normalized transverse emittance is 120 π.mm.mrad. The longitudinal emittance is 15 π.deg.MeV and the energy spread is $\pm$2.2 %.

Introduction

A compact electron storage ring (Kaken Storage Ring, KSR) is now under construction at the Institute for Chemical Research, Kyoto University [1]. The layout of the accelerators is shown in Fig. 1. The KSR has a race track shape and its maximum beam energy is 300 MeV. It will be used as the synchrotron radiation source from the dipole magnet and the insertion device. The critical wave length of the synchrotron radiation is 17 nm. It will be also used for the research of the free electron laser.

The construction of the linac had been finished and we succeeded to accelerate the electron beam of 140 mA in October, 1995. The design beam energy is 100 MeV and the pulse width is variable from 10 nsec to 1 μsec. Table 1 shows the main linac parameters. The linac will be also used for the experiments of the coherent X-ray generation by the election beam. Especially, the parametric X-ray radiation (PXR) experiment has been already started.

Table 1 Beam parameters and main specifications of the linac.

Output Electron Beam	
Energy	100 MeV
Max. Pulse Width	1 μsec
Max. Repetition	20 Hz
Electron Gun	
Cathode Assembly	Y-796 (Eimac)
Max. Extraction Voltage	-100 kV DC
Accelerating Structure	
Bore Radius	11.74 - 13.4 mm
Length	3 m
Operating Frequency	2857 MHz
Maximum Electric Field	15 MV/m at 20 MW

Accelerator

The electron gun has the Pierce electrode and the cathode assembly is the Y-796 (Eimac). The maximum extraction voltage is -100 kV. The pre-buncher is a single reentrant cavity. It is designed to bunch the beam within the phase spread of 60 degree. The buncher is a disc-loaded and 3 step constant gradient structure. It has 21 cells and the total length is 777 mm. The designed phase spread is within 3 degrees at the beam current of 100 mA when the input power is 12 MW.

There are three main accelerating structures. The main characteristics of the accelerating structure are also listed in

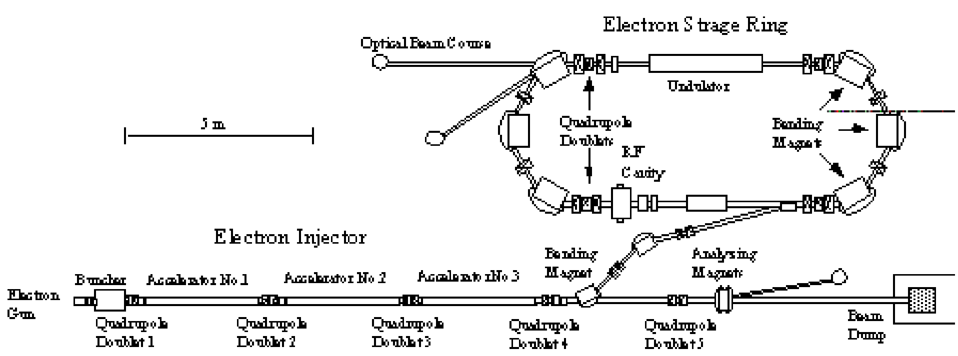

Figure 1 Layout of the electron accelerator.

table 1. The maximum electric field is 45 MV per an accelerating structure without beam loading at the input power of 20 MW. The doublets of the quadrupole magnets are used as focusing elements between the accelerating structures.

Klystron

There is a klystron for each accelerating structure. The total number of the klystron is 4 including the buncher, pre-buncher system. The klystron is ITT-8568. The maximum output power is 21 MW and the pulse width is 2 µsec. We are going to replace the klystron with Mitsubishi PV3030A2. The present modulators and the focusing coils are reused for the new klystrons so that the replacement cost and time can become minimum. The solenoid is a single electromagnetic coil and generates the magnetic field of 0.9 kGauss on the axis. Figure 2 shows the relation between the cathode voltage and the output power. The output power of 30 MW is available at the cathode voltage of 250 kV. The power efficiency is 48 %.

Beam Measurement

The beam emittance and the energy is measured downstream of the linac. Figure 3 shows the schematic view of the beam monitor section. The beam current is measured by the current transformer (CT) with ferrite core. The main components in this section are two profile monitors (PM1, PM2). They consist of screens, CCD cameras and an image memory unit. The image data is analyzed by the computer in the control room. The material of the fluorescence screen is an alumina ceramic in which a little chromium oxide is homogeneously doped (Desmarquest, AF995R). PM1 is used for the measurement of the transverse beam profile and the emittance. PM2 is used for the measurement of the energy spread and the longitudinal emittance.

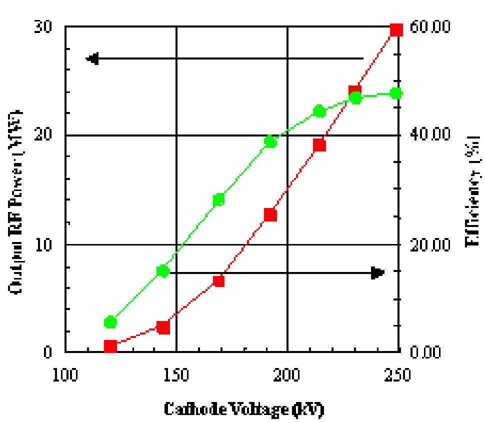

Figure 2 RF output power and the efficiency of the klystron (PV3030A2). The pulse width is 2µsec.

Transverse Beam Profile and Emittance

The shape of the beam distribution in the transverse phase space is assumed,

$$\gamma x^2 + 2\alpha x x' + \beta x'^2 = \varepsilon \, , \qquad (1)$$

where α, β, γ are Twiss parameters and ε is the transverse emittance. The Twiss parameters are transformed from QD to PM1according to the following equation.

$$\begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix}_{PM1} = \begin{pmatrix} m_{11}{}^2 & -2m_{11}m_{12} & m_{12}{}^2 \\ -2m_{21}m_{11} & 1-m_{12}m_{21} & -2m_{12}m_{22} \\ m_{21}{}^2 & -2m_{22}m_{21} & m_{22}{}^2 \end{pmatrix} \begin{pmatrix} \alpha \\ \beta \\ \gamma \end{pmatrix}_{QD} \qquad (2)$$

where m.. are elements of a transfer matrix between QD and PM1.

$$\begin{pmatrix} x \\ x' \end{pmatrix}_{PM1} = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}_{QD} \qquad (3)$$

From the formula (2), the rms beam radius σ at PM1 is obtained.

$$\begin{aligned} &\sigma^2{}_{PM1} = m_{11}{}^2(\varepsilon\beta) - 2m_{11}m_{12}(\varepsilon\alpha) + m_{11}{}^2(\varepsilon\gamma) \\ &(\varepsilon\beta)\cdot(\varepsilon\gamma) - (\varepsilon\alpha)^2 = \varepsilon^2 \end{aligned} \qquad (4)$$

where the Twiss parameters are values at QD. We measure the beam size by the profile monitor (PM1) with various field gradient of QD and calculate the emittance by the least square fitting.

Figure 4 shows the relation between $\sigma_{PM1}{}^2$ and the field gradient of QD. The beam current is 100 mA and the pulse width is 100 nsec. It is the operation mode of the beam injection into the KSR. The unnormalized emittance at QD is 0.57 π.mm.mrad and the normalized value is 120 π.mm.mrad.

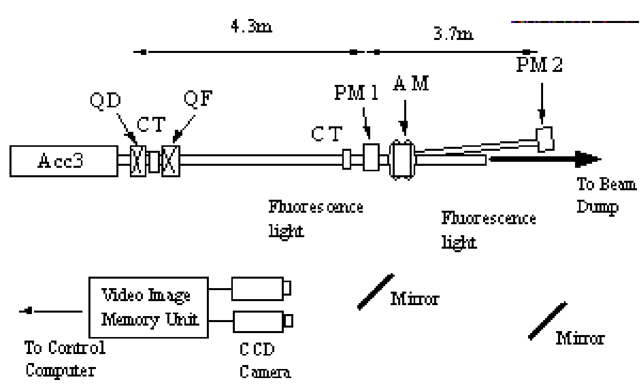

Figure 3 Schematic view of the beam monitor section downstream of the linac.
Acc3:Third accelerating structure, CT:Current transformer,
QD,QF:Quadrupole magnets, PM1,PM2:Profile monitors, AM:Analyzing magnet.

Energy Spread and Longitudinal Emittance

The beam energy spread is measured by the profile monitor (PM2) downstream of the 5 degree analyzing magnet. The rms beam radiusσ at PM2 is,

$$\left\langle s_{PM2} \right\rangle^2 = \left\langle x_b \right\rangle^2 + \left\langle h \frac{dp}{p} \right\rangle^2 \qquad (5)$$

where η is the dispersion and is 0.15 m. The first term is due to the transverse emittance and it is calculated from the measured data. The second one due to the energy spread. The correlation is assumed to be negligible between the two terms. The measured beam profile at PM2 is shown in Fig 5. The beam current is 100 mA and the pulse width is 100 nsec. The center beam energy is 109 MeV and the energy spread is +2.2 %.

To observe the longitudinal emittance, the phase of the last accelerating structure (Acc3) is set so that the relativistic electron beam go through it with the synchronous phase of zero. The transfer matrix from Acc3 to PM2 is,

$$\begin{pmatrix} q \\ E \end{pmatrix}_{PR2} = \begin{pmatrix} 1 & 0 \\ V_{rf} & 1 \end{pmatrix} \begin{pmatrix} q \\ E \end{pmatrix}_{Acc3} \qquad (6)$$

where θ and E are relative phase and energy to the synchronous particle. In this formula, the approximation is used because the synchronous phase is zero.

$$V_{rf}\ \sin(q) \approx V_{rf}\, q \qquad (7)$$

Similar to the formula (4), the relation of the rms energy spread, longitudinal emittance and Twiss parameters is,

$$\begin{aligned} \langle E \rangle^2{}_{PM2} &= m_{21}{}^2 (eb) - 2 m_{22} m_{21} (ea) + m_{22}{}^2 (eg) \\ (eb)\cdot(eg) - (ea)^2 &= e^2 \end{aligned} \qquad (8)$$

The energy spread is measured with various RF voltage (Vrf) and the longitudinal emittance is calculated by the least square fitting.

Figure 6 shows the relation between the square of rms beam radius at PM1 and the RF voltage of Acc3. The beam current is 100 mA and the pulse width is 100 nsec. The center beam energy is 71 MeV. The longitudinal emittance is 15 π.deg.MeV. The phase spread is+8.0 degree.

References

[1] A.Noda, et al., "Electron Storage Ring, KSR for Light Source with Synchrotron Radiation" , Proc. of the Particle Accelerator Conference, Dallas, USA, 278 (1995)

[2] T.Shirai, et al., "A 100 MeV Injector for the Electron Storage Ring at Kyoto University" , Proc. of the Particle Accelerator Conference, Dallas, USA, 1079 (1995)

[3] N.Sereno, et al., "Bunch Length Measurements at the Advanced Photon Source (APS) Linear Accelerator" , Proc. of the Particle Accelerator Conference, Dallas, USA, 1070 (1995)

[4] Y.Bylinsky, et al., "Longitudinal Emittance Measurement of the 100 MeV Proton beam" , Proc. of the Particle Accelerator Conference, San Francisco, USA, 3062 (1991)

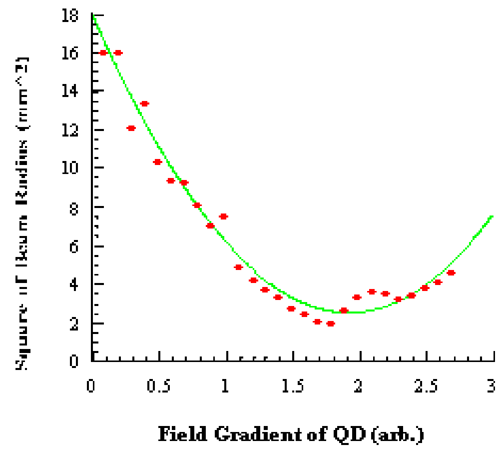

Figure 4 Relation of the square of the rms beam radius and the field of the quadrupole magnet (QD). The solid line shows a best fit curve.

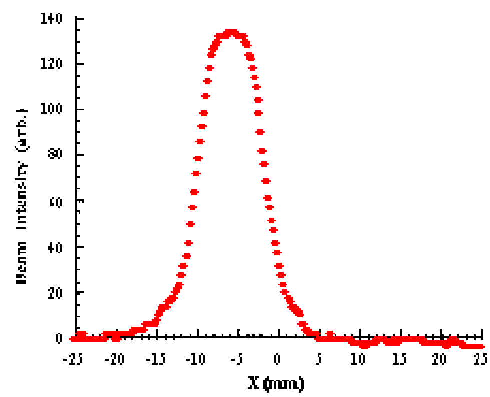

Figure 5 Beam profile at the profile monitor (PM2) downstream of the analyzing magnet.

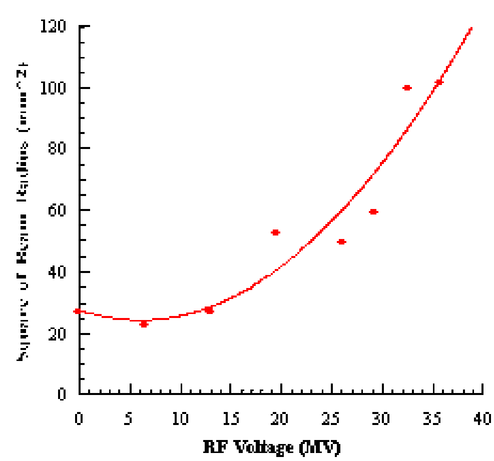

Figure6 Square of rms beam radius at the profile monitor (PM2) as a function of the Acc3 RF voltage .