COMPACT STORAGE RING "NIJI-IV" FOR UV FEL EXPERIMENT

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Abstract

Outline of a 500-MeV compact storage ring "NIJI-IV" with a 6.2 m long optical klystron for the ultra-violet FEL experiment is described. NIJI-IV has a hexagonal configuration with a circumference of 29.6 m, consisting of two cells of the triple bend achromat lattice. It will be completed in 1990 on the basis of the works on compact storage rings and the visible FEL conducted in the Electrotechnical Laboratory(ETL), jointly with the Kawasaki Heavy Industries, Ltd. (KHI).

Introduction

With the increasing demand for tunable ultra-violet (UV) lasers available for photon-induced chemical processes, free electron laser (FEL) is recently receiving much attention in Japan due to its feasibility of high power and wide tunability covering a quite wide range of wavelength from mm to UV. The photon-induced chemical processes using UV FELs will bring about prospective industrial applications, since tunable UV FELs can control photon-induced chemical reactions more precisely than available excimer lasers can do.

After the successful operation of 3.4 mm FEL using the super-conducting linac at Stanford Univ. in 1977[1], FEL oscillations have been achieved in the visible range using ACO ring at Orsay in 1983[2], and in the UV range ($\sim$240 mm) using VEPP -Ⅲ ring at Novosibrisk in 1988[3]. Recently the FEL is considered as sufficiently mature in the FIR and IR spectral ranges. To my knowledge, seven projects of FELs near the IR and the visible ranges using linacs are favored for SDI projects and two projects of the UV range using a 185-MeV NIST microtron and a 1-GeV storage ring under construction at Duke Univ. in the USA.

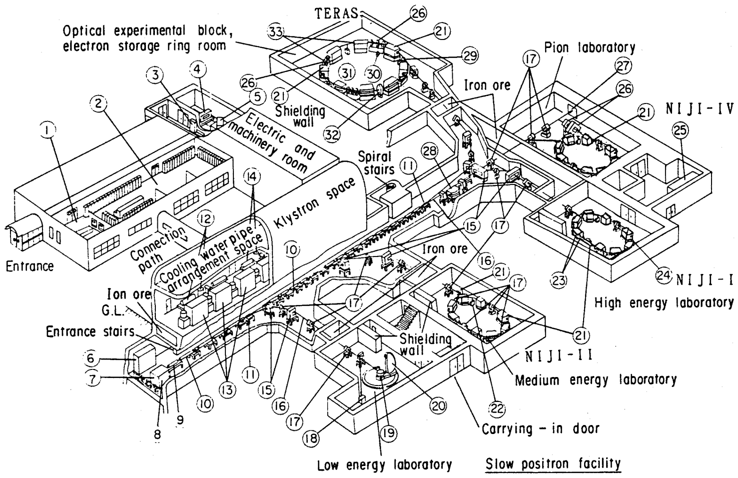
The FEL of the UV range needs many technologies such as accelerater physics of storage ring and linac, FEL physics, optical technology including optical cavity, mode propagation and diagnosis, magnet technology for a long optical klystron, optical elements and so on. The UV FEL sources available for chemical industries in the near future, however, should be compact and operated easily as the compact storage rings proposed and developed for ULSI lithography[4] and angiography[5].

Through the developments of compact storage rings for these purposes and the visible FELs using a 1.47 m optical klystron[6], we have accumulated key technologies needed for the compact strage ring for the UV FELs reported here.

In this paper, we present outline of a 500-MeV compact storage ring with a 6.2 m optical klystron for UV FEL experiment. It will be constructed in 1990 on the basis of key technologies on compact storage rings and the visible FEL accumulated in ETL, jointly with KHI.

Technical Backgrounds

Figure 1 shows the 500-MeV ETL Linac and Storage Ring Facilities. The 500-MeV Linac and buildings have been constructed in 1980[7]. The linac can accelerate a high energy - high power electron beam in the energy range of 10$\sim$400 MeV. A 75-MeV beam is used to produce high



(1) Management room (2) Measurement and control room (3) Betatron control room (4) Pair spectrometer (5) Betatron (6) Electron gun pulser (7) Electron gun (8) Ion pump (9) Buncher (10) accelerating section, lens, and ion pump cooling pipe arrangement (11) Pulsed deflection coil (12) Accelerating section cooling device (13) Klystron pulser (14) Klystron cooling device (15) Bending magnet (16) Vacuum duct and cooling pipe arrangement (17) Quadrupole magnet and ion pump (18) RI irradiation equipment (19) Scattering chamber and ion pump (20) Compton spectrometer (21) NIJI-IV (22) Ion pump (23) Beam line (planning) (24) NIJI-III (25) Magnet power supply (26) Quadrupole magnet for pion channel (27) Beam catcher (28) ECS magnet (29) Turbo molecular pump (30) Sputter ion pump (31) Ti getter pump (32) RF accelerating cavity (33) SR beam line

Fig. 1 Layout of the ETL Linac and Storage Ring Facilities intensity slow positrons. Electrons of 90～320 MeV are injected into four compact storage rings; TERAS, NIJI-Ⅱ, NIJI-Ⅲ and NIJI-Ⅳ(NIJI-means rainbow).

TERAS has been operated on Oct. 1981[8]. ETL has also operated three compact rings, NIJI-Ⅰ～Ⅲ, jointly with the Sumitomo Electric Industries (SEI); that is, NIJI-Ⅰ has been operated on Feb. 1986[9,10], NIJI-Ⅱ on Aug. 1989[11),12] and NIJI-Ⅲ on June 1989[13]. NIJI-Ⅱ and NIJI-Ⅲ have been developed as soft x-ray sources used for 0.25 μmscale ULSI fine processing.

The visible FEL experiment has been also continued in ETL using a 1.47 m optical klystron installed in the 1.8 m straight section of TERAS. Total system including an optical cavity was completed on Aug. 1989. The length of the optical cavity is 5.238 m. Therefore, three bunch operation at 240 Mev is needed when the visible FEL experiment is carried out. The cavity loss is less than 1×10^{-4} and a gain per pass of 1×10^{-4} for 2 mA bunch current at 570 nm is obtained. The present system including TERAS, however, can yield a gain per pass of 1×10^{-3} at most at the visible region because of the short straight section of TERAS.

Compact Storage Ring NIJI-Ⅳ

NIJI-Ⅳ should be compact and its straight section where an optical klystron can be installed is long enough to generate the UV FEL. The choice of the magnetic lattice is also important to achieve the beam storage of low emittance, small energy spread, high current, and dispersion free at the optical klystron.

Figure 2 shows ratios of the length of straight section Ls to the cell length of the magnetic lattice Lc as a function of Lc on the existing and planned storage rings worldwide[14]. The closed circles show the storage rings of triple bend achromat lattice, the open circles double achromat lattice, the closed square FODO lattice, the open square triblet achromat lattice, and the closed triangle extended double bend achromat lattice. the solid line of Ls=6 m indicates storage rings with 6 m straight section. New storage rings of the third generation such as ALS, APS, ESRF, SPRING(Kansai), SRRC(Taiwan), Pohang(Korea), TRIESTE(Italy) near this line can install many 5 m undulators to generate high brilliant radiations. The lattice of these rings is triple achromat type or double achromat type. The both lattices can achieve dispersion free drift spaces for insertion devices.

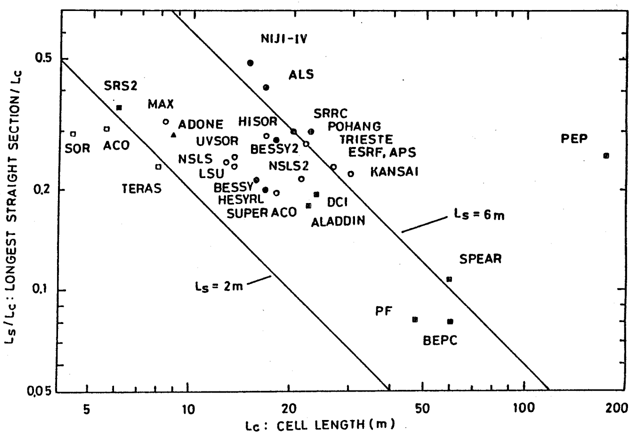


Fig. 2 The ratio Ls/Lc as a function of Lc on the existing and planned storage rings.

In the case of compact storage rings with two cell structure of these lattice, however, the triple bend achromat type can yield lower emittance beams because the emittance is inversely proportional to the cube of the number of dipole magnets. Ditailed study on the choice of the magnetic lattice is given in elsewhere[15].

Figure 3 shows a schematic layout of NIJI-Ⅳ. It is a 500-MeV conventional type compact ring with straight sections longer than 7 m where a 6.2 m optical klystron can be installed to generate the UV FELs. NIJI-Ⅳ has a hexagonal configuration with a circumference of 29.6 m, consisting of the two cell structure of the triple bend achromat lattice. The magnetic structure is a combination of six 60° dipole magnets(ρ =1.2 m, n=0) with the same entrance and exit angle of 16.1° and twelve quadrupole magnets. The lattice order is 0/2 Qf Qd Bd Qf Bd Qf Bd Qd Qf 0/2 and the periodicity is two. The betatron and dispersion functions for one superperiod of the lattice are shown in Fig. 4. One of the long dispersion free spaces is used for the 6.2 m optical klystron. The 162.1 MHz old RF cavity previously used for TERAS will be used as an RF cavity. The harmonic number is sixteen. A stored current higher than 60 mA is expected at two bunch operation. The calculated beame mittance is 5×10^{-8} m.rad. at 350 MeV.

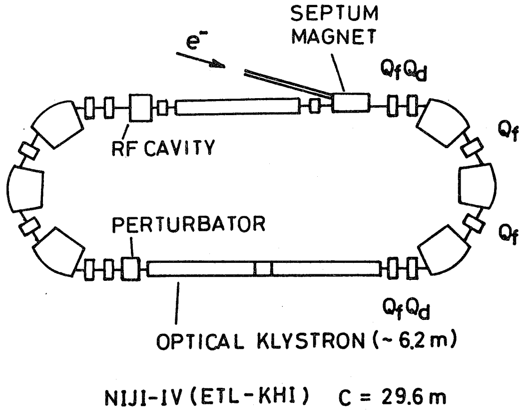


Fig. 3 Schematic layout of NIJI-Ⅳ.

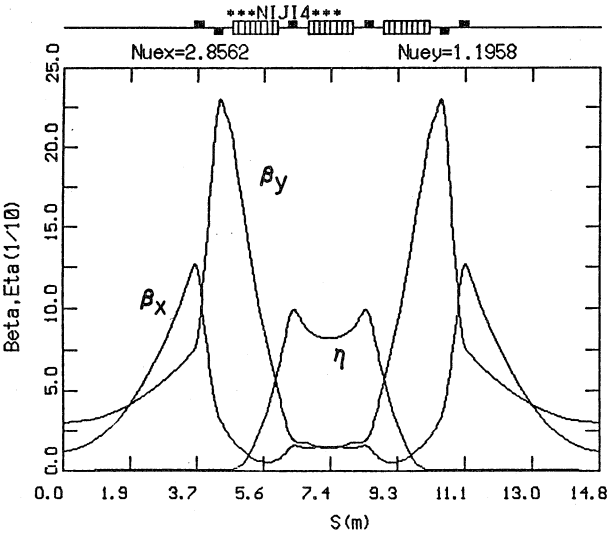


Fig. 4 Betatron and dispersion functions of NIJI-Ⅳ.

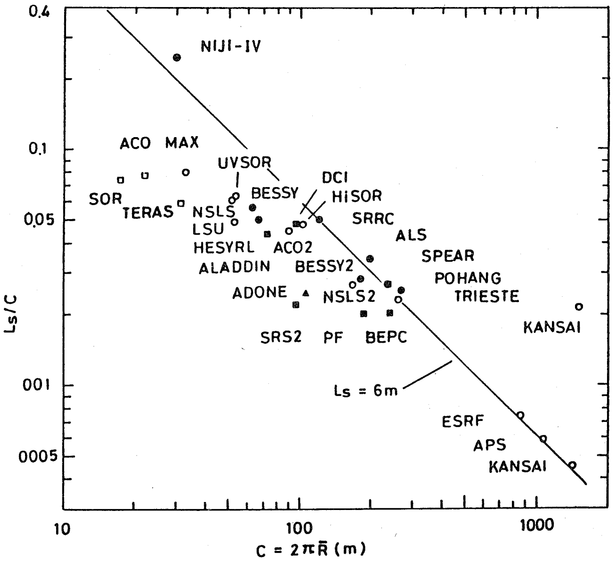


Fig. 5 The ratio Ls/C as a function of C on the existing and planned storage rings.

Figure 5 shows ratios of the length of straight section Ls to the circumference C as a function of C on the existing and planned storage rings worldwide. NIJI-IV is the most compact ring with 7 m long straight section.

6.2 m Optical Klystron

THe FEL wavelength λR is related to a wiggler magnet period λ_0 of an optical klystron and to the electron energy γ in units of rest mass m_0c^2 by the resonance condition

$$\lambda R = \lambda_0(1+K^2/2)/2\gamma^2, \qquad (1)$$

where $K = 93.4B(T)\lambda_0(m)$ with B being the peak magnetic field at the wiggler midplane. For instance, B = 0.315T, λ_0 = 0.07 m, γ = 560 (286.2 MeV) gives λ = 348 nm from Eq.(1). A gain per pass of the optical klystron for a wavelength λR given by Eq.(1) is [16]

$$G^{TOK} = 1.12\times10^{-13}\lambda_0^2(N+Nd)N^2K^2\gamma^{-3}(JJ)^2 f\rho F_f \qquad (2)$$

where N is the number of wiggler magnet periods, Nd the number of periods of light of wave length λ passing over an election in the dispersion section, JJ the Bessel function factor, f the modulation rate, ρ the peak electron density in m^{-3}, and Ff a filling factor due to the electron and light beams all along the optical klystron.

For an electron energy spread of 7×10^{-4}, the value of Nd attains 100. Therefore, the gain per pass given by Eq.(2) is roughly proportional to the square of the length of the optical klystron L_0 for the length L_0 shorter than 10 m since $L_0 = 2N\lambda_0 + 3\lambda_0$, where $3\lambda_0$ is the length of the dispersion section.

Figure 6 shows a shematic layout of the 6.2 m optical klystron, whose main parameters are as follows; the total length is 6.2 m, λ_0 is 70 mm and N = 43. A gain per pass higher than 2.3 % is expected for 350 nm at 20 mA bunch current from Eq.(2) and a scaling law obtained from the gain measurement of the visible FELs.

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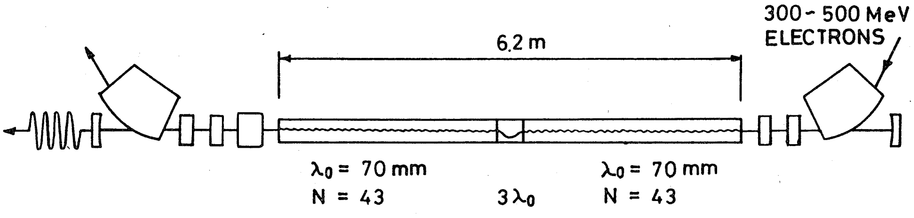

FIG.6 Schematic layout of 6.2 m optical klystron.