A 600-MeV ETL Electron Storage Ring

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Summary

A 600-MeV electron storage ring has been constructed in only ten months at a cost of 200 million yen at the Electrotechnical Laboratory (ETL) in Tsukuba. The 500-MeV high efficiency-high current electron linac being operated for high energy-dosimetric experiments serves as an injector. The ring consists of eight bending magnets (r = 2m) and four triplets of quadrupole magnet. The circumference is 31.45 m and λ_p is 22 Å. The lattice order is O/2 $B_d Q_f Q_d Q_f B_d$ O/2. The harmonic number is 17. The maximum stored current is 160 mA and 1/e lifetime is 1.5 hours at present. The radiation is used for calibrating photometry and soft X-ray standards, photoelectric analysis of electronic materials, and LSI lithography.

Introduction

The first storage of electrons was achieved on Oct. 7, 1981. The 500-MeV high efficiency-high current electron linac[1] being operated for high energy spectro-dosimetric experiments serves as an injector. The ETL storage ring is a type of accelerating and storage like "ACO"[2]. Therefore, the ETL ring is called TERAS, the Tsukuba Electron Ring for Accelerating and Storage. Terasu is a Japanese verb meaning "to illuminate". On the other hand, the ETL linac is called TELL, the Tsukuba Electrotechnical Laboratory Linac. Teru is also a Japanese verb meaning "to shine" and (William) Tell is an expert archer in a famous tale. The combined facility is known as TELL-TERAS.

Although TERAS was completed in a short time of ten months, the plan for construction of both linac and ring had been in progress for ten years prior to the actual moving of ETL to Tsukuba Science City. The preliminary design study[3] of TERAS was performed by the late Dr. F. Sugawara (ETL) and Prof. T. Yamakawa (INS) in the early stage of this plan. They designed a 600 MeV ring with eight bending magnets with tapered poles of a field index n = 0.5 and four triplets of quadrupole magnet. Their design of the magnet structure followed quite closely that of ACO. The four triplet system is one of the strong focusing systems needed to store high beam current. However, the weak focusing using the bending magnets with tapered poles is not essential in the storage ring and besides it is quite difficult to keep the field index n = 0.5 at any magnetic field along radial direction of the pole piece as long as iron core is used. Therefore, the bending magnets with tapered poles were not adopted.

The ETL Storage Ring "TERAS"

The final magnet structure is a combination of eight homogeneous-field magnets with a same entrance and exit angle of 11.7° and four triplet strong focusing systems. The advantages of this design are three fold: First, the fabrication of the homogeneous-field magnet is of course easy, second, the handling is very easy because of no field correction and third, some position tolerances in the radial direction of the magnets are relaxed.

Fig. 1 shows the layout of TERAS and beam lines for experiments. TERAS consists of eight 45° bending magnets (n = 0, r = 2m), four triplet focusing systems, a septum magnet, a kicker coil, an RF cavity and

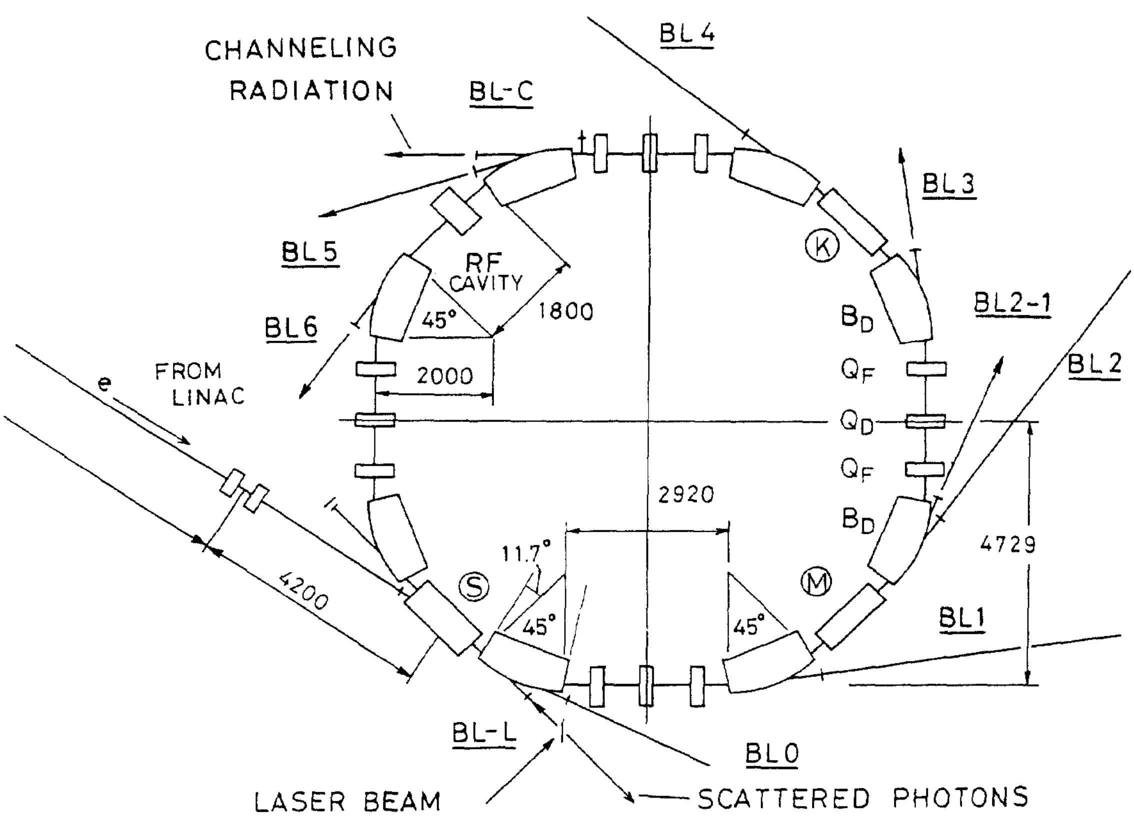

Fig. 1 Layout of TERAS and Beam Lines for Experiments.

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ultrahigh vacuum system. The circumference is 31.45 m. The main parameters of TERAS are shown in Table 1. The vertical focusing is provided by the edge angle 11.7° of the bending magnets B_d and four quadrupole magnets Q_d, while the horizontal focusing is provided by eight quadrupole magnets Q_f. The lattice order is 0/2 B_dQ_f-$Q_dQ_fB_d$ 0/2. Furthermore, four sextupole magnets will be installed in this year.

The Q-value of the re-entrant type RF cavity is 1100 at a frequency of 162.1 MHz and the RF power needed to store a beam current of 100 mA at 600 MeV is about 1.4 kW. The harmonic number is 17. More than 90 % of the electrons injected and stored at 300 MeV can be accelerated up to 600 MeV in a few minutes using an interlocking controller of the power supplies for B_d, Q_f and Q_d. The final target of the energy gain is 2.6 ($\sim$800 MeV).

Improvement of the ultrahigh vacuum system was done to increase total pumping speed and beam lines for experiment in Jan. 1983 as shown in Fig. 2. Total pumping speed of the mounting and built-in pumps has been increased up to 13000 l/s from 8000 l/s. The pressure in the vacuum chamber is kept less than 2×10^{-10} Torr at low stored current.

The stored current is monitored by a silicon photo diode (SPD) detecting synchrotron radiation (SR). The SPD monitor was calibrated by the single electron decay step method using a photomultiplier tube (PM)[4]. The PM monitor can clearly detect a variation of the SR intensity caused by one electron loss in stored beam of several hundred electrons.

The size of the stored beam is always monitored viewing the focused SR spot with a TV monitor. The beam size can be changed adjusting exciting current supplied to Q_f or Q_d. The 1/e lifetime of the stored beam is longest for round beam cross section as shown in Fig. 3. The maximum stored current is 160 mA and 1/e lifetime is 1.5 hours at present. Fig. 4 shows relations between stored current and 1/e lifetime and between stored current and pressure.

Table 1

( ) shows final target

Max. energy	600 MeV (800 MeV)
Stored current	150 mA (300 mA)
Circumference	31.45 m
Radius of curvature	2.000 m
Average radius	5.000 m
Lattice	$0/2B_dQ_fQ_dQ_fB_d0/2$
No. of dipole magnets	8
No. of quadrupole magnets	12
No. of sextupole magnets	(4)
Betatron freq.	$\nu_x \simeq 2.2$ $\nu_z \approx 1.3$
Rf freq.	162.1 MHz
Rf power	1.4 kW at 600 MeV-100 mA

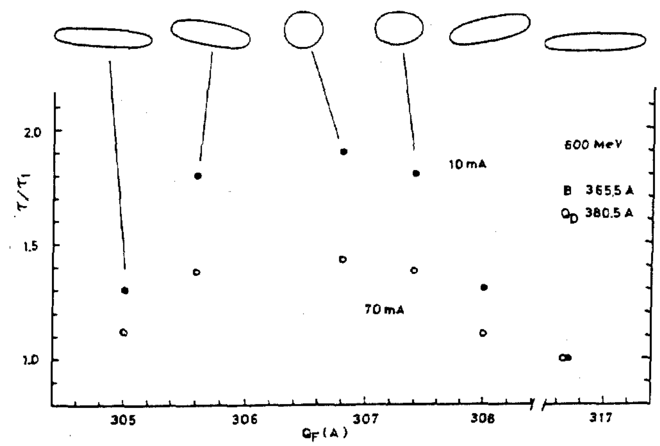

Fig. 3 Beam Size and 1/e lifetime.

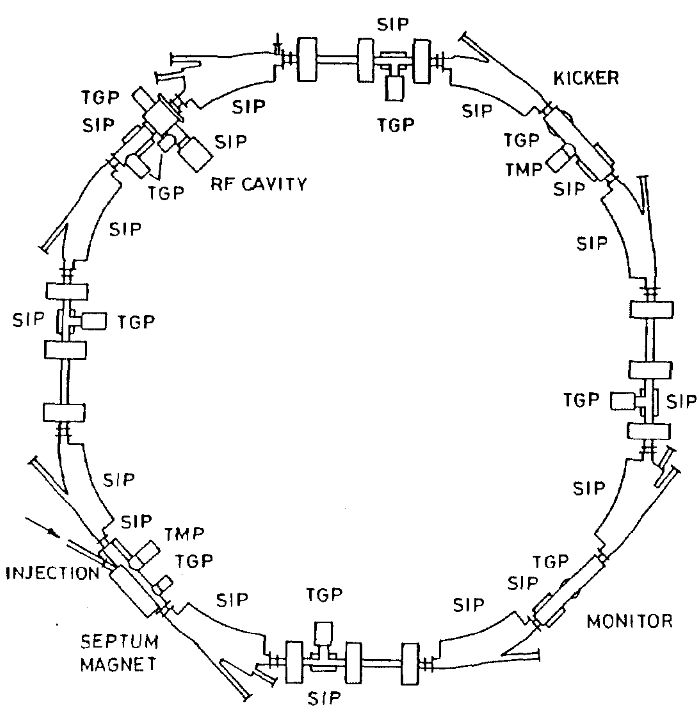

Fig. 2 Vacuum System for TERAS.

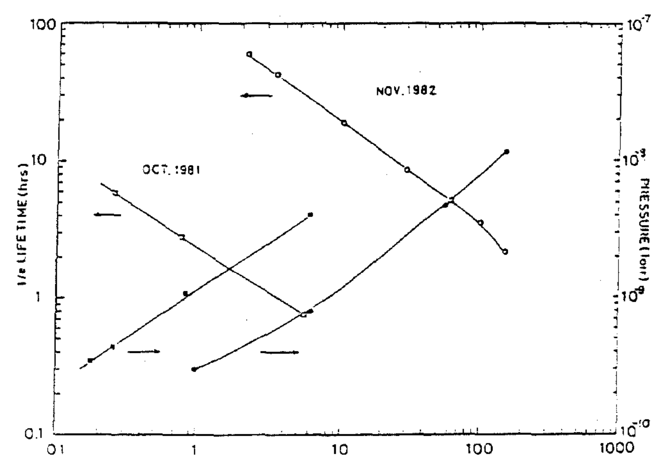

Fig. 4 1/e lifetime and Pressure vs Stored Current.

Injection System

300-MeV electrons are provided at a rate of a pulse per 0.64 seconds from TELL being operated at 50 ~ 600 pps for high energy dosimetric experiments using a 5°-deflect pulsed coil and a beam transport system 40 m long[5]. Fig. 5 shows the layout of the electron injection system from TELL to TERAS. The 5°-deflect pulsed coil (PC) is designed to deflect electrons of momentum up to 400 MeV/c by an angle of 5.5° at a rate of a pulse per 0.64 seconds. The beam transport system consists of two 31° bending magnets (DBS-1, 2), five quadrupole doublets (QD-1 ~ 5), two vertical steering coils (STC-1, 2), a horizontal steering coil (STC-3), vertical and horizontal steering magnets (STM-1, 2), and three beam position monitors (BPM-1 ~ 3). To find out optimum operating parameters of these coils and magnets, the beam position monitors[4] observing optical transition radiation are effectively used. The spot size and the position of electron beam are measured by observing transition radiation from a 0.5 mm thick Al foil on which vertical and horizontal scales are marked. On the foil of the monitor BPM-3 at the position 65 cm upstream from the inlet of the ring, beam intensity is about 20 nano Coulomb per pulse (1 μsec) and the beam size is 5 mm (horizontal) by 3 mm, which is small enough when compared to the size (15 mm x 8 mm) of the inlet of the septum magnet. Injected electrons passing through the small bending gap of the septum magnet are monitored using the ETL type quantameter (Q-II)[6]. The maximum fill rate achieved so far is 15 mA/min at present.

Fig. 5 Layout of Electron Injection System from TELL to TERAS.

Beam Lines for Experiments

Six beam lines (BL 1, 2, 3, 4, 6 at 8°, BL 5 at 15°) are used at present and four beam lines are prepared. Fig. 1 shows these beam lines and the purpose of the two beam lines BL-C and BL-L. BL 1 is used for calibrating photometry standard, BL 2 for calibrating soft X-ray standard and to study electronic materials using VUV spectrometers and UPS, and BL 4 for LSI lithography. Other three beam lines (BL 3, BL 5 ~ 6) are used for stored current monitoring and beam profile measurement. New beam lines BL-0 and BL 2 – 1 (22.5°) are used for beam control and machine study. Other new beam lines BL-C and BL-L (0°) are used to study laser Compton scattered photons and to yield channeling radiation[7].

The authors would like to thank Dr. E. Teranishi, Chief of Quantum Technology Division, for his encouragement throughout this longstanding work. They greatly appreciate the contribution of the late Dr. F. Sugawara (ETL) and Prof. T. Yamakawa (KEK at present) in the early stage of the design work.

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