COMPACT ELECTRON STORAGE RING "NIJI-1"

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ABSTRACT

A compact electron storage ring "NIJI-1" has been constructed and satisfactorily operated since Feb. 28, 1986. The storage of electron current more than 340 mA of 160-MeV electrons has been achieved on March 7, 1978. The 1/e lifetime of a 300-mA beam is about 1 hour. Some descriptions are given on the structure of "NIJI-1", several improvements made to increase the stored current, and the current lifetime and stability at energies lower than 100 MeV.

INTRODUCTION

Synchrotron radiation (SR) emitted by high-energy electrons in a circular motion is expected to be indispensable for 0.25μm scale ULSI fine processing in the 1990's and analytical evaluation of materials by vacuum ultraviolet photoelectron spectroscopy, as a unique strong soft X-ray source. Development of compact SR rings for these purposes are in progress in West Germany, France, Japan and the USA. In Japan two kinds of compact-SR ring project are being developed. One is mainly by the ETL and the Sumitomo Electric Industries Ltd and the other mainly by the Nippon Telegraph and Telephone Corporation (NTT). However, it is the feature of the ETL project that the SR ring is an electron undulating ring [1] capable of large-area exposure of SR. The design study of a compact SR ring was started in the summer of 1984 and the ETL jointly completed with the Sumitomo Electric Industries, Ltd. a compact test ring NIJI-1 (rainbow in English) measuring four meters in mean diameter in the medium energy laboratory of the ETL Linac Facilities as shown Fig.1. We have succeeded in the first-beam storage on Feb. 28, 1986[2] and already achieved the storage of electron current more than 340 mA of 160-MeV electrons.[3] This is a successful result of a joint government-private sector research project sponsored by the Agency of Industrial Science and Technology. The researches, such as high-efficiency injection of low-energy electrons, miniaturization of the electron injector, are steadily advanced.

DESCRIPTION OF THE STORAGE RING "NIJI-1"

The magnetic structure of NIJI-1 is composed of eight bending magnets and four long and short straight sections as shown in Fig.2. In each long straight section (S_1, S_3, S_5, S_7), two radial-focusing quadrupole magnets (Qf) are installed. In each short straight section (S_2, S_4, S_6, S_8), one vertical-focusing quadrupole magnet (Qf) is installed. Electrons transported from the medium energy section of the linac "TELL"[4] are injected into NIJI-1 by using a septum magnet (located in S_1) and a kicker magnet (located in S_5) which performs a bumped orbit. The RF cavity is installed in S_7 and the RF power is suppled through a coaxial feeder from a 2-kW power amplifier to the cavity. The detailed description of the RF cavity and its performance is given elsewhere in the Proc. of this Conference. The beam position monitors are attached at long straight sections (S_3, S_5, S_7). AD current transformer

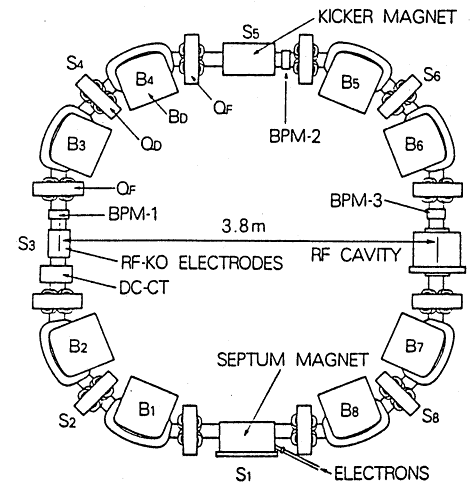

Fig.2. Plane view of NIJI-1.

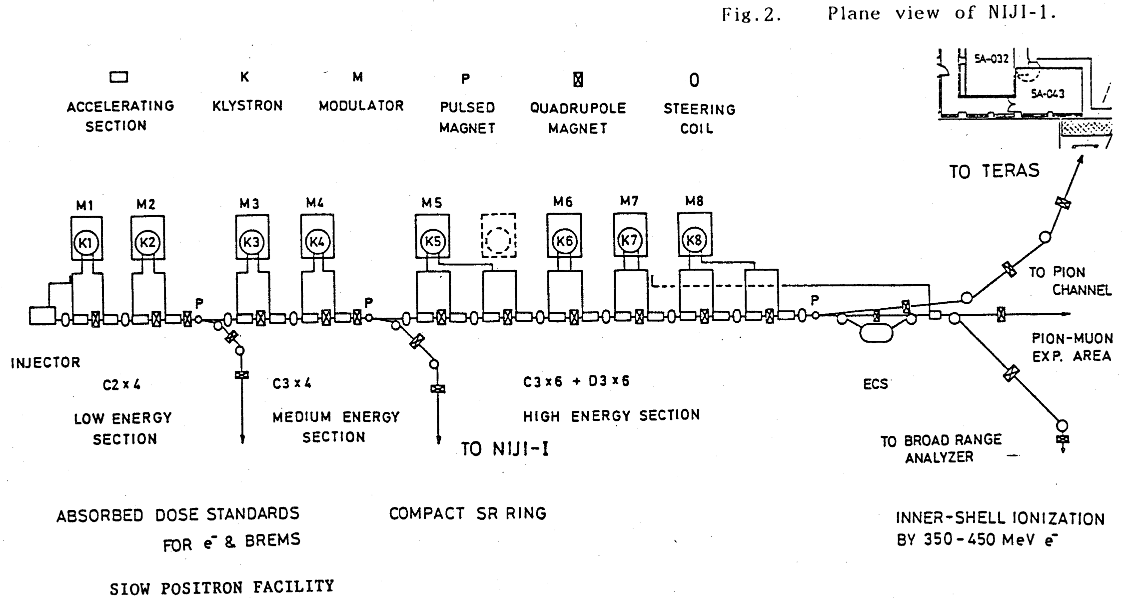

Fig.1. The ETL Linac Facilities.

measuring the electron beam current and electrodes of the RF knockout system are set in S_3. The main parameters and the structure of lattice functions of NIJI-1 are shown in Tab.1 and Fig.3.

Generally speaking, the high-efficiency injection of low-energy electrons is not easy because of a short lifetime of stored beam due to the Touschek effect. Since the Touschek lifetime is proportional to the reciprocal of the density of stored electrons, the cross section of the beam should be made large enough to allow for a long life-time. The cross section becomes large in the condition of a vertical extention of the beam volume due to a coupling between radial and vertical betatron oscillations and also for a large dilation (or momentum compaction factor). Therefore, the field index n of the eight bending magnets was chosen to be 0.5 (the measured value 0.47).
In addition to the n-value of 0.47, since the vertical focusing is provided by the 12° edge angle of each bending magnet, the actual focusing force required for the quadru-pole magnet Qd is so weak that it might be possible to omit Qd quadrupole magnets. Though the operating point, at which a long lifetime is kept, is not accommodated with the point at which the high-efficiency injection is achieved, an optimum condition can be obtained by adjusting the exciting current supplied to QF or QD.

The vacuum system for NIJI-1 and SR beam ports are shown in Fig.4. The total pumping speed of the de-mountable pumps is 7300 l/s. The built-in supper ion pumps are not set in the chambers of the bending sections. SIP, TGP and IG stand for sputter ion pump, titanium getter pump and ionza-tion gauge, respectively. In order to reduce the circumfer-ence of the ring keeping the high pumping speed, SIP and TGP of each bending section and each straight section are set outside or inside the ring as shown in Fig.4. The vacuum chamber of the bending section was specially designed so as to mount SIP and TGP outside of the ring as shown in Fig.5. SIP and TGP are mounted at the bottom and top of the outside part of the chamber. The position of these pumps is also effective for high gas desorption induced by high intensity SR. A typical value of the residual gas pressure is about 0.3 nTorr at the gauge positions except for the RF cavity.

Table 1. Main parameters of NIJI
( ) shows final target

Injection Energy	~160 MeV
Maximum Energy	230 MeV (600 MeV)
Repetition Rate	50/32 pps
Circumference	13.256 m
Focusing Order	0/2 Qf Bd Qd Bd Qf 0/2
Periodicity	4
Bending Radius	0.7 m
Bending Field	0.76 T
Horizontal Betatron Tune	$1.2 < \nu_x < 1.8$
Vertical Betatron Tune	$1.2 < \nu_x < 1.8$
Harmonic Number	7
Radio Frequency	158.4 MHz
Maximum RF Power	2 kW
Stored Beam Current (on March 19, 1987)	344 mA (500 mA)

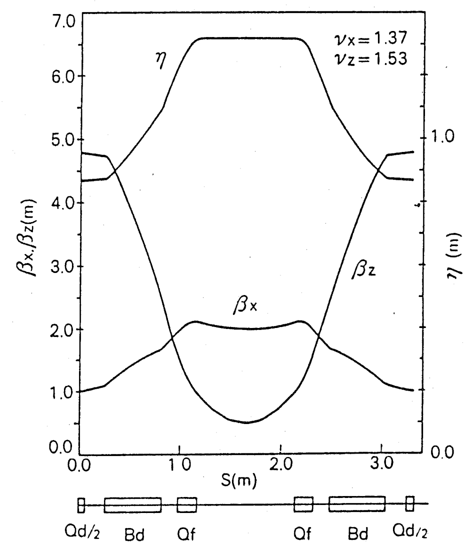

Fig.3. Structure of lattice functions at present operating point.

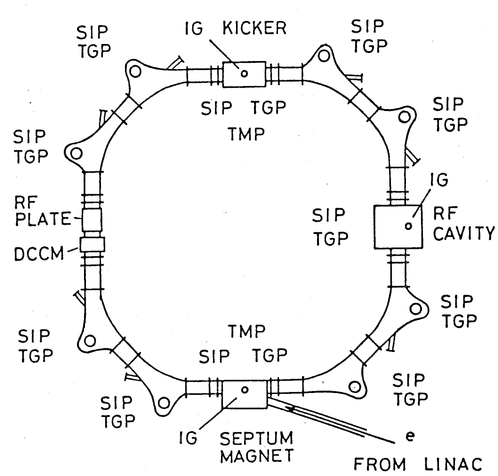

Fig.4. Vacuum system for NIJI-1.

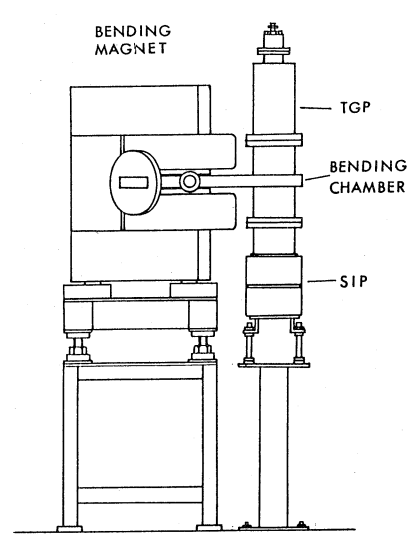

Fig.5. SIP and TGP mounted at the bottom and top of the chamber.

STORED BEAM CURRENT AND LIFETIME

Since the first beam storage on Feb. 28 in 1986, the following improvements have been made to increase the stored current.

(1) Additional steering magnets were attached to the beam transport system to do a fine adjustment of the beam position and direction.

(2) Horizontal and vertical closed orbit distortions were corrected with exciting trim coils of the bending magnets by using the beam position monitors.

(3) Injection efficiency was considerably improved by adjusting the position of the septum and kicker magxnet.

(4) The electrodes of the beam position monitor were used as the ion clearing electrodes to clear up the ions trapped in the stored beam.

Usually, the injection of 163 MeV electrons is carried out with the operating point of the ring chosen as $\nu_x = 1.37$, $\nu_z = 1.53$.

The change in the 1/e lifetime of the stored current is shown in Fig.6. The maximum stored current of 163-MeV electrons so far obtained was 344 mA and the lifetime was about 50 min, while the average pressure of the ring reached 5×10^{-9} Torr. This was due to radiation-induced gas desorption. The result implies that the increment of the stored current and the lifetime becomes larger after the more sufficient time-integrated current of the ring.

To estimate the lifetime at lower energies, the energy of the stored electrons was decreased by decreasing the exciting current of Bd, Qf, Qd with an interloking controller of the exciting current. The lifetime obtained at 51.6 MeV and 80 MeV shown in Fig. 6 is significantly longer than expected from the empirical formula on the current lifetime product $I_0\tau_T$ given by the following equation,[5]

$$I_0\tau_T = \alpha E^4. \qquad (1)$$

The reason why such a long lifetime has been observed at low energies seems to be due to a large cross section of the stored beam of more than one order compared with the case of TERAS. The results suggest the possibility of the electron injection at lower energies.

BEAM SIZE AND ION TRAPPING

NIJI-1 is a type of acceleration and storage. Electrons injected and stored at a low energy can be accelerated up to the final energy stage using an interlocking controller of the power supplies for Bd, Qd and Qd. The field change induces the eddy current in the vacuum doughnuts and in the magnets made of iron, which possibly disturbs the uniform magnetic field. However, the stored beam at 163 MeV was accelerated up to 230 MeV in 7.2 sec. A field change of 0.046 T/sec didn't cause any beam loss.

A stored current limit and/or variation of beam cross-section are caused by the ions trapped in the stored beam. The so-called ion trapping phenomena were also observed in NIJI-1. The ions induced by SR and electrons are trapped in a potential well produced by the stored electron beam and interact with the stored electrons. With the increase of the stored current, the vertical blow-up due to the ion trapping was observed by viewing the focused beam spot with a TV monitor as shown in Fig.7. As the stored beam did not rise above 120 mA without DC electric field applied to clear the ions trapped in the stored beam, a DC clearing voltage of -400 V was applied on the electrodes of the beam position monitors during the subsequent injection. As a result, the vertical beam size was reduced as shown in Fig.7 and the maximum stored current of 344 mA was achieved. The increase in the stored current limit was accomplished by the ion clearing. Therefore, during the electron injection above 120 mA and also after the injection, the DC voltage is applied to clearing electrodes to keep a longer lifetime. Fig.8 shows the current dependence of the beam size transverse σ_x and σ_z with DC voltage and without DC voltage. A detailed investigation of the phenomena has not been done ret.

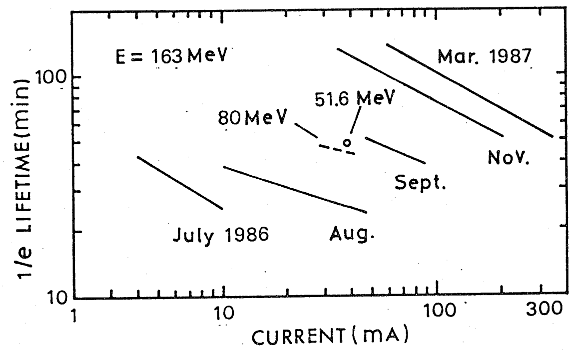

Fig.6. Lifetime of stored beam current.

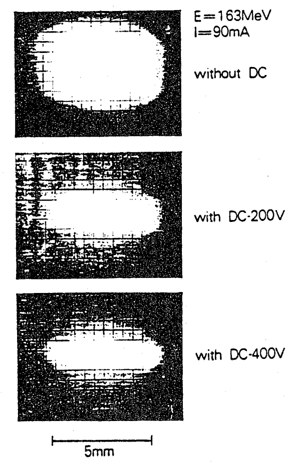

Fig.7. Beam profile.

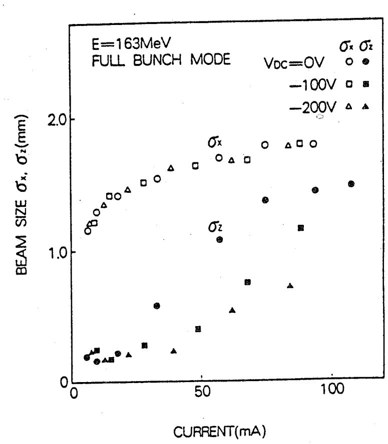

Fig.8. Measured beam size against current.

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