The Recent Improvement of TERAS

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Abstract

Some advancements were made to TERAS for increasing the injection efficiency and the accumulation of the electron beam. They included the beam stabilization for the longitudinal coupled-bunch instability. The improvements were carried out in order to develop the a 10-T superconducting wiggler for a digital subtraction angiography. The injection efficiency achieved is more than 1 mA per the injection pulse. The electron beams of 450 mA at 300MeV were successfully accumulated. The utilization for users of TERAS is usually made less than 300 mA at 750 MeV.

Introduction

TERAS is an 800 MeV electron storage ring dedicated to the synchrotron radiation. Radiation from the infrared up to several keV in energy is used for a spectro-radiometric standardizations in VUV and soft X-ray region, wide variety of experiments in the field of atomic, molecular and solid physics, and the development of USLI lithography. The first lasing at 598 nm of storage-ring FEL was also succeeded in 1991 at TERAS[1]. The storage ring includes one polarizing undulator and a quasi-monochromatic gamma-ray facility by Compton backscattering on laser light[2]. These insertion devices are used as monochromatic radiation sources and their operations depend strongly on the quality of electron beam. A 10-T superconducting wiggler is also going to be installed and be operated. The development of the 10-T superconducting wiggler has been proposed to generate sufficient intensity of 34-keV photon required for digital subtraction angiography[3]. The improvements of the storage ring were carried out to store the high intense beam current stabilized for the purpose of the operation of the superconducting wiggler.

Two important problems in operating TERAS should be mentioned: the low injection efficiency and the limitation of the accumulation of electron beam. These operating conditions of the storage ring were considered to come from distortions of close orbit. The distortion of closed orbit disturbs dynamically incident electrons and reduces the injection efficiency. It also gives rise to the beam instability due to its enhancement of the interaction of electron beam with its surroundings; for instance, the rf cavities. The experiments of measurement of bunch length were carried out at TERAS several times until now. The results of these experiment indicated the bunch lengthening with low threshold current, and implied the longitudinal coupled-bunch instability. In order to get the better of the performance of TERAS, we decided to look over the whole of the storage ring before setting up the superconducting wiggler having strong magnetic field.

The refinement of the machinery arrangement of TERAS

The center of the quadrapole magnetic field were detected, and the axis of the magnetic field were assigned as to be in line with the design trajectory of electron beam. Quadrupole magnets are located with the precision is less than ±0.05 mm. The quadrupole magnet systems have been affected by the change of the building basis and earthquake lasting many years after the construction of TERAS. Their position have undergone fluctuation, which have resulted in serious effect on the beam injection, the accumulation, and the acceleration of electron energies from the injection beam energy to 750MeV.

The rf cavity system of TERAS consists of the main cavity and the Landau cavity with 2-nd harmonics[4]. The rearrangement of th rf system was made so that electron beams travel through the center part of the accelerating electrodes of the cavities. This adjustment was of use to reduce the generation of wake field induced electron beam passing off axis of the rf cavities. Such situation can be concluded from the fact that the synchrotron sidebands of the signal from the pick-up antenna in the rf cavity are not able to be observed in wide range of stored currents.

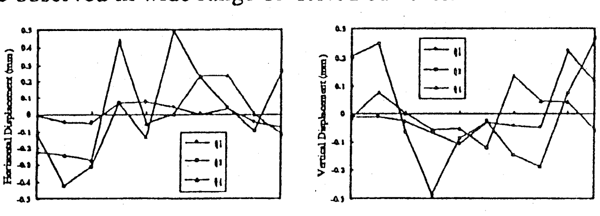

Fig. 1 The displacement of transverse beam positions

Four button-type beam position monitor system has been installed at four places in along the circumference of the storage ring[5]. Calibration of all monitors was made in laboratory with 171.6 Mhz. An antenna was set at the position and used to measure the for electrode outputs. The mapping of the four electrode calibrations was made use of to monitor the beam positions. In order to reduce the distortion of closed orbit, the adjustment of beam trajectory was made by using the position monitor system and controlling the collection magnet. The horizontal and vertical orbit excursions are shown in Fig. 1 and reduced to ± 0.5 mm and $\pm$ 0.3 mm respectively.

Beam performance and beam life

A typical injection and operation pattern of the storage ring are shown in Fig. 2. It takes only four or five minutes to accumulate the beam of 300 mA for the injection energy of 307 MeV. The repetition rate of the injection system is 2 Hz. After filling the electron energy is successfully accelerated up to 750 MeV. It takes less than 10 minutes to ram up the electron energy. Figure 2(b) is a plot of the decay rate as a function of beam current at 750 MeV. The curve measured is described by a power function with an exponent of 2.0. The figure shows that the beam life time is dominated by the multiple scattering of electrons on residual gas molecules[6]. As the result of the residual gas analysis with Q mass sensor, H_2 and CO molecules amount over 90 % of the residual ones. It suggest that CO molecules are trapped in stored beam currents and cause the betatron tune shift. The residual gas analysis prompt us to measure the betatron tune shift and to take some means to reject the ion trapping effect.

Figure 3 shows the dependences of the pressure and the beam lifetime for the beam current of 100 mA upon the amount of the time-integrated beam current from the first operation of the ring after last evacuation. The beam lifetime continues to increase gradually up now. Photo clearing effect in the vacuum chamber is very useful to make residual gas pressure decrease and to increase the beam life time. It however takes long time to increase the life time by this method because the injection energy of TERAS is 300MeV and the power of SR is small.

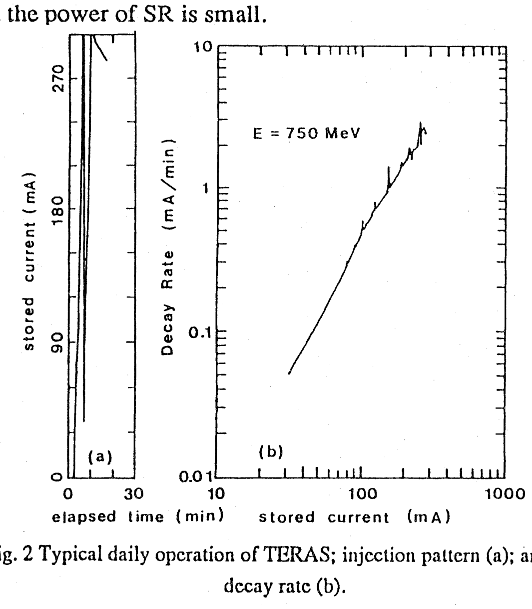

Fig. 2 Typical daily operation of TERAS; injection pattern (a); and the decay rate (b).

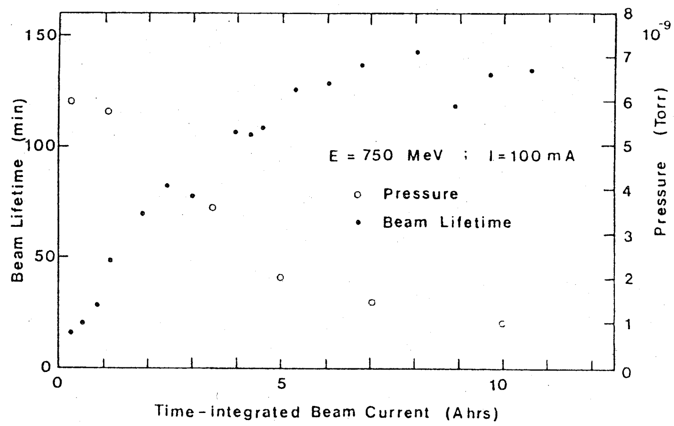

Fig. 3 Decrease of the pressure and improvement of beam lifetime during the operation of TERAS.

Measurement of betatron tune shift

The ion trapping effects at TERAS have been previously measured. The results measured showed the betatron tune shift due to the ion trapping effect in the storage ring[7].

The cure for the ion trapping effect has been taken at TERAS by putting the ion clearing electrodes in the vacuum chamber. The DC clearing system consists of argon glow discharge electrodes which are set inside the vacuum chamber of bending magnets at a distance of about 5 cm from the electron beam trajectory. The electrostatic field is also supplied onto a pair of parallel plates of the RF-KO system. Three four-button type electrodes for beam position monitor are also used for ion clearing system. The different type of ion clearing electrodes are also set in the vacuum chamber. The voltage supplied is adjusted effectively to reduce ion trapping effect. Optimized voltage is found to be around 1200 V .

The betatron tune shifts on beam current was measured at 750 MeV. The results obtained are shown in Fig. 4 as a function of electron beam current. It is noted that vertical betatron tune increases with increasing beam current, the other hand, horizontal betatron tune has almost constant values with stored current. The slope of straight line of vertical betatron tune shift exhibits the positive tune shift and suggest that positive ion trapped in the path of electron beam act as focusing force on electron beam. The stored beam feels the potential induced by trapped ions and the potential varied with according with the density of ions. By assuming the Gaussian distribution of ions having the standard deviations σ_x and σ_y of electron beam, the expression for the tune shift with standard formula due to the ion trapping effect can be given by

$$\Delta\nu_{xy}=\frac{r_e}{\gamma}\int\frac{d_i}{1+\sigma_y/\sigma_x}\beta(s)ds$$

where r_e, is the classical electron radius; γ,is Lorentz factor; d_i, is the number density of ions (m^{-3}); and $\beta(s)$, is betatron amplitude. The ion densities can be obtained from the results of the tune shift measurements. The ion density for 130 mA at 750 MeV is estimated to about $5x10^{13}/m^3$. This value is approximately five times as large as the one obtained from the average gas pressure of the storage ring. It is concluded that the local gas pressure has a lot of effect on the electron beam.

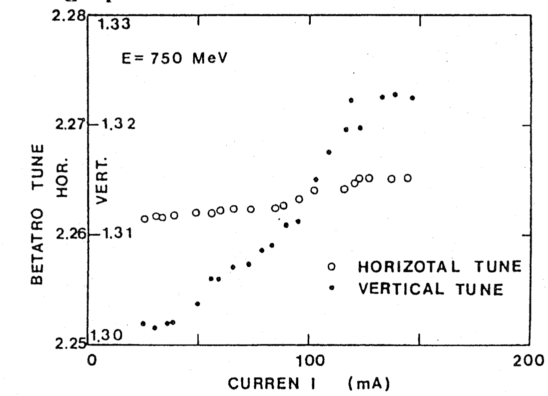

Fig. 4 The betatron tune as a function of the beam current at 750 mA.

Bunch length measurement

As mentioned before, the experiments to measure the bunch lengthening have been made to investigate the longitudinal instability of electron beam[8]. The experimental results indicated that TERAS has two components of coupling impedance with large values. The beam instability is considered to be caused by interaction of electron beam with its surroundings, for instance, the rf cavity. The measuring instrument used is a Hamamatu-photonics streak camera. Some of the time-resolved spectra viewed with the streak camera are shown in Fig. 5. The bunch shape however tends to deviate from a Gaussian at high current. The date of bunch shape was taken as a function of average current, at the fixed rf cavity voltage at 750 MeV. Figure 6 is a plot of bunch length as a function of beam current at 750 MeV. The part of the curve measured at low current is described by a power function with exponent of 0.14, but the other part at high current has a power function of 0.4. The figure shows that the bunch lengthening in TERAS result from two different causes. The one corresponds to the curve represented by a power function with exponent of 0.14 and has the threshold current of 3.5 mA. The other one explains the other part of the curve described by a function of $I^{0.4}$ arises from the threshold current of 70 mA; I, beam current.

The two components of longitudinal ring impedance extracted from the threshold currents obtained for the 750 MeV data give the following values; $|Z/n| = 11.5\,\Omega$ for $I_{th} = 3.5$ mA, and $|Z/n| = 0.37\,\Omega$ for $I_{th} = 70$ mA. The longitudinal ring impedances obtained are so small compared with the ones measured before and described in ref. 8; 46 Ω and 105 Ω. This improvement results from the rearrangement of the rf cavity system and leads the stable operation of TERAS.

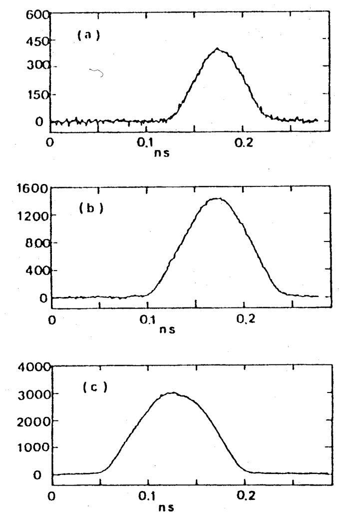

Fig. 5 The electron bunch shapes taken by multisweep operation of the streak camera at 750 MeV at 31.3 mA (a); at 145 mA (b); and at 239 mA (c).

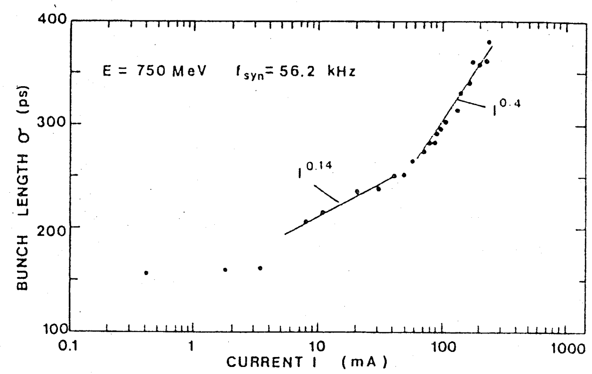

Fig. 6 A plot of bunch length as a function of beam current at 750 mA.

Conclusional remarks

There has been a great progress of the operation of TERAS. The injection efficiency has been grown up almost ten folds, which has produced good result of the increase of stored current. It also facilitates the wide varieties of our experiments, for instance, the development of 10-T superconducting wiggler. The lifetime of electron beam at 100 for 750 MeV at present about 2.5 hour, and continues to be on the increase.

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