The 6th Symp. on Accelerator Science and Technology, 1987, Tokyo, Japan (© Ionics, Tokyo, 1987)

STATUS OF SOR-RING

Y. Miyahara
Synchrotron Radiation Laboratory, University of Tokyo,
3-2-1, Midori-cho, Tanashi, Tokyo, 188

ABSTRACT

Here are briefly reported recent investigations in SOR-RING about a longitudinal instability and its landau damping with a double RF system, transport properties of trapped ions, Touschek effect of a round beam, and synchro-betatron resonance associated with a nonlinear resonance.

LONGITUDINAL INSTABILITY AND LANDAU DAMPING

In SOR-RING the electron beam suffers from a longitudinal instability, and the bunch length increases as 1/6 power of the beam current.$^{1)}$ The instability is induced by a coupled bunch interaction with a broad band impedance. The threshold current is 0.24(3.0) mA at a beam energy of 308(380) MeV. The bunch lengthening can be well explained as an equilibrium state between the growth rate of the instability and Landau damping due to synchrotron frequency spread. The spread is produced by the non-linearity of the RF potential.

In order to suppress the instability a second harmonic cavity (Landau cavity) was installed in the storage ring,$^{2)}$ which produces a wide frequency spread. Because of the synchronous phase $\phi_s \cong 180$ of the main cavity, the optimum phase for the widest frequency spread is obtained by setting the Landau cavity voltage as $\phi_{sL} \cong 0$ and $V_{LC} \cong V_{MC}/2$ against the main cavity voltage V_{MC}. In the double RF system the tuning angle is varied manually in both cavities, and the synchronous phase of the Landau cavity can be kept constant by a phase feedback loop.

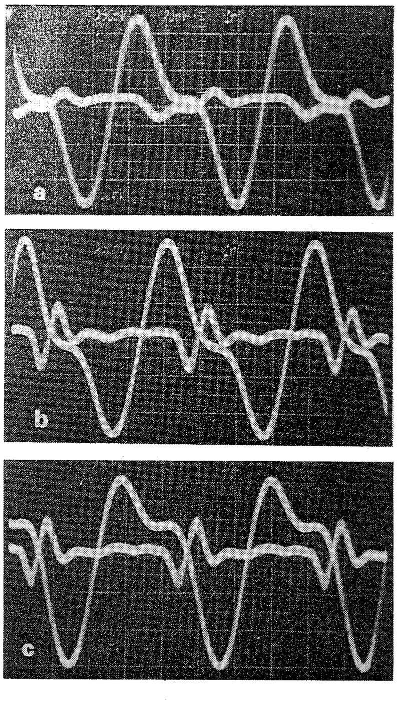

Fig.1 Beam bunch and total RF voltage in double RF system. Beam bunch (time derivative) slips from optimum phase (a) forward (b) or backward (c) by Robinson instability.

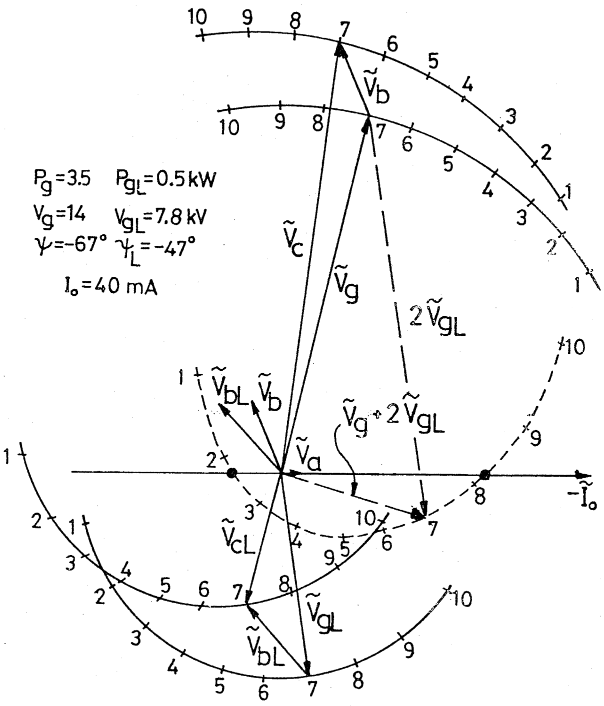

Fig.2 Phase diagram in double RF system.

At first the experiment was performed without the phase feedback as has been done successfully in the proton storage ring ISR. The longitudinal instability was surely suppressed, but only at a beam current below 30~50 mA. Above this current another phase instability was induced; the beam bunch slipped away from the optimum phase forward or backward in the RF phase, which accompanied a simultaneous deformation of the total voltage as shown in Fig.1. In such a situation the longitudinal instability is no longer suppressed.

The unexpected phase slip can be explained by Robinson instability. Since the radiation energy of the electron beam should be compensated by the RF voltage in synchronous phase, the relation among the radiation energy U, cavity voltage V_c, generated voltage V_g, and induced voltage V_b is determined uniquely. Figure 2 shows the relation on the phase diagram, where the suffix L indicates the quantity for the Landau cavity, and the same numbers on trajectories represent the state satisfiying the above relation. According to the stability criterion of the Robinson instability, the beam bunch is stable if the vector sum $\tilde{V}_g+2\tilde{V}_{gL}$ locates on the upper half plain of the diagram. Therefore beam bunch is expected to slide from the optimum but unstable state #5 toward the stable state #2 or 8, with a simultaneous deformation of the total voltage. Calculated total voltages for the state #5, 2 and 8 are close to the observed voltages in Fig.1.

Next the phase feedback loop was turned on, then the beam bunch was fixed at the optimum phase, and the longitudinal instability was suppressed up to a beam current of 110 mA at 308 MeV. This is not much different from the maximum threshold current which can be expected in the present double RF system as discussed below.

From the equilibrium condition between the growth rate and Landau damping the threshold current in the double RF system is determined by

$$\frac{I_{th}}{I_{tho}} = \frac{3}{8}\,\frac{\Delta\Omega_s}{\Omega_s}\left(\frac{A_L}{A_0}\right)^3\left(\frac{L_{RF}}{A_0}\right)^2 \tag{1}$$

where Ω_s and $\Delta\Omega_s$ are synchrotron frequency ant its spread, L_{RF} the bucket length of the main RF cavity, A the half bunch length, and suffix o indicates the quantity at the threshold without the Landau cavity.

The RF potential $\Phi(\tau)$ is flattened at the center of the RF bucket, anf the synchrotron frequency of the electron with effective energy E_i^*, proportional to the square of electron energy, is determined by

$$\frac{\pi}{\Omega_s(E_i^*)} = \int_{\tau_1}^{\tau_2}\frac{d\tau}{\sqrt{2(E_i^*-\Phi(\tau))}} \tag{2}$$

where τ is the deviation in time from the synchronous phase, τ_1 and τ_2 are the maximum excursion in the potential. The energy spread of the electron beam is determined by the synchrotron radiation, which depends on the magnet lattice but not on the RF potential. Then the bunch length determined by the maximum excursion for the highest energy E_{imax}^* is $A_L/A_0=2.7$ at 308 MeV, and the frequency spread is $\Delta\Omega_s/\Omega_s=0.19$. Therefore we expect from Eq.(1)[5] a threshold current of 155 mA in the double RF system.

ION TRAPPING

In the storage ring there have been traces of ion trapping in the electron beam; 1) vertical beam size increases as the beam current, 2) RF knock out becomes harder as the beam current, 3) beam lifetime is considerably shorter than that expected from residual gas scattering and Touschek effect.

Trapped ions can be eliminated by applying a dc voltage to clearing electrodes. To investigate properties of the trapped ions, a pulsed voltage was applied to a position monitor, which was used as a clearing electrode, and γ-ray intensity was monitored with a scintillator at several positions around the ring[3] at a beam current of 150~200 mA. The γ-rays are emitted by the interaction of trapped ions and electron beam. For the pulsed voltage the γ-ray intensity is reduced substantially in a few ms,(Fig.3) and the reduction becomes slower as the distance. From the half decay time of the intensity the rms velocity is found to be 950 m/s, which is by 3.3 times faster than the thermal velocity of CO^+ ions. The reduction becomes lesser as the distance, indicating that the transmission of trapped ions decreases as the distance. It can be shown that by ExB force in the bending field the drift velocity is changed substantially in the absolute value and in the sign depending on the initial condition of trapped ions. The reduction of γ-ray intensity depends much on the voltage of distributed ion pumps in bending magnets, even if monitored pressures in the ring remain the same.

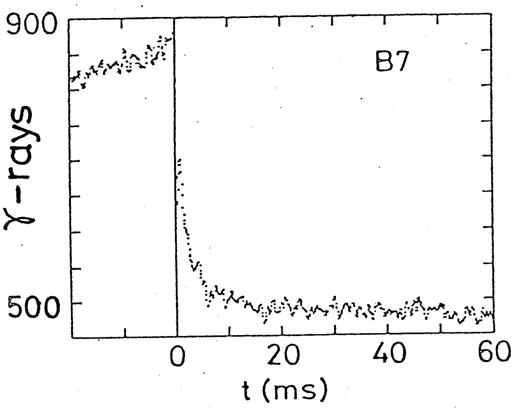

Fig.3 Reduction of γ-ray intensity for a pulsed voltage applied to a clearing electrode.

TOUSCHEK EFFECT

Touschek lifetime is expected to be lengthened by increasing bunch volume. The beam lifetime in the storage ring was really increased by exciting a skew quadrupole magnet, which couples horizontal and vertical betatron oscillations and increases the bunch volume. This has been confirmed in a sigle bunch operation, where beam bunch is stable since no instability is induced (Fig.4). The lifetime is, however, longer two times than expected from the lifetime formula commonly used. The reason is that the formula only takes into account horizontal betatron oscillation. Including vertical oscillation we[4] find the following formula for a round beam,

$$\frac{1}{\tau_T} = \frac{2\pi r_0^2 c}{\gamma^4}\,\frac{D(\varepsilon)}{\sigma_x'\sigma_z'}\,\frac{N_B}{V_B}\,\frac{1}{\Delta E_m/E} \tag{3}$$

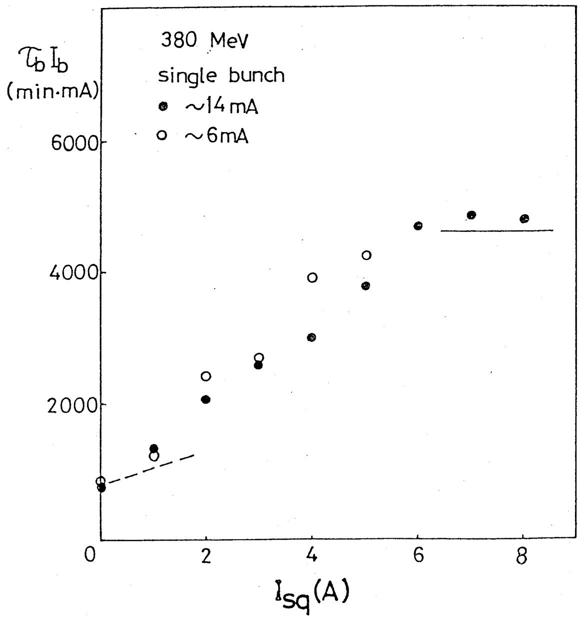

Fig.4 Beam lifetime against skew quadrupole current in a single bunched beam. Broken and solid lines are the calculated Touschek lifetime for a thin and a round beam, respectively.

where r_0 is the classical electron radius, c the light velocity, N_B the number of electrons per bunch, γ the relativistic energy, σ_x' and σ_z' the horizontal and vertical divergence V_B the bunch volume and $\Delta E_m/E$ the RF bucket height. $D(\varepsilon)=1/\sqrt{\varepsilon}-6$ with $\varepsilon=(\Delta E_m/E)^2/2(\delta g_x)^2$ and δg_x the momentum spread. Figure 4 shows that this agrees with the experimental value. In a multi bunch operation the vertical beam size is already increased considerably at a higher beam current probablly by ion trapping effect, so that the effect of the skew magnet is not remarkable.

SYNCHRO-BETATRON RESONANCE

With the skew magnet being excited in a multi bunch operation, the lifetime decreases substantially in some cases at a higher beam current as shown in Fig.5. This is caused by synchro-betatron resonance. Horizontal and vertical betatron tunes ν_x and ν_z shift considerably as the skew field strength, and happen to touch to the resonance line $2\nu_x+2\nu_z-m\nu_s=5$ on the tune diagram (see Fig.6), where ν_s is the synchrotron tune and m is integer. The resonance width measured by changing the RF voltage is about 4×10^{-4} at a beam current of 100 mA and decreases as the decrease of the beam current. Similar synchro-betatron resonances have been observed with respect to several nonlinear resonances around the operation point. The resonances becomes stronger at a higher beam current, and induce beam loss up to m=±4. Because of $\nu_s=0.006$ the good operation point free from the resonances are limited in narrow regions.

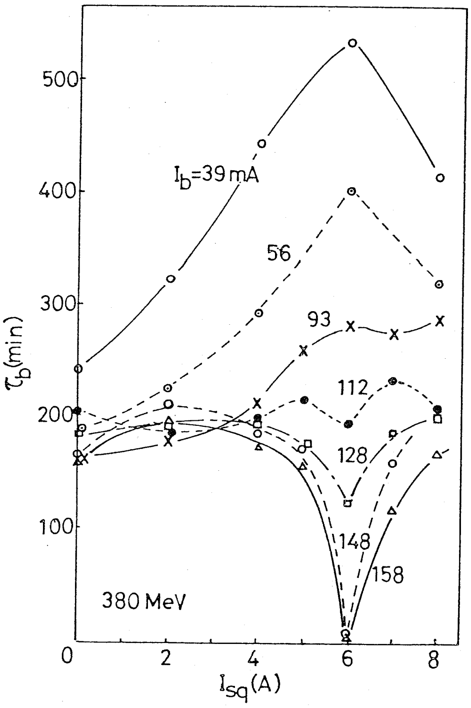

Fig.5 Beam lifetime against skew quadrupole current in a multi bunched beam.

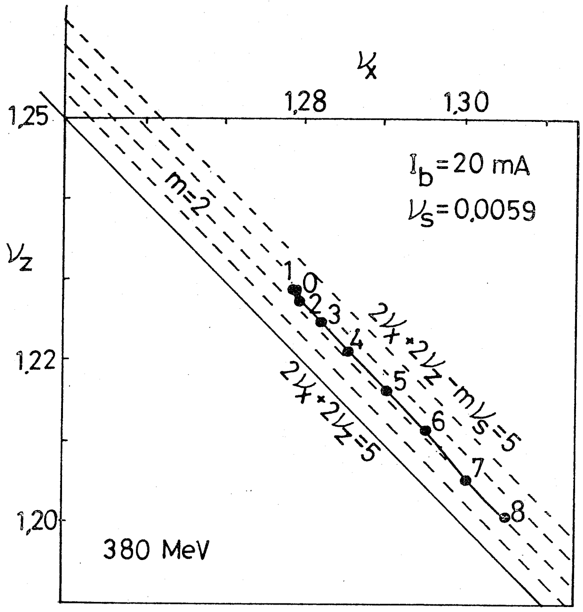

Fig.6 Tune shift for skew current I_{sq}=0~8 A.

REFERENCES

1) S.Asaoka etal, Nucl. Instr. and Methods 215 (1983) 493.
2) Y.Miyahara etal, Jpn. J. Appl. Phys. 22 (1983) L733.
3) K.Watanabe etal, submitted to Jpn. J. Appl. Phys.
4) Y.Miyahara, Jpn. J. Appl. Phys. 24 (1985) L742.