SUPPRESSION OF LONGITUDINAL COUPLED-BUNCH INSTABILITY IN UVSOR

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Introduction

The UVSOR is a 750 MeV electron storage ring used solely for vacuum ultraviolet synchrotron radiation research in molecular science and related fields. A longitudinal coupled-bunch instability excited by higher-order-mode resonances of the RF cavity had already been observed when the routine operation of the ring was started. Two methods to cure the instability was tried, i.e. a feedback method and a decoupling method. The former system consists of sixteen independent feedback loops; each of them corrects the energy deviation of one of sixteen bunches, individually. The system can suppress the instability, however, the critical adjustment is required, i.e. the feedback loops have to be finely adjusted according to parameters such as the electron energy, the beam current and the RF acceleration voltage. The latter system spreads synchrotron frequencies of individual bunches by means of the modulation of the effective acceleration voltage in order to decouple these synchrotron oscillations. The instability is damped by this method when the beam current is not high (I_{beam} < 100 mA). The limitation of this method is not in the principle but in the maximum modulation index available in the experiment. Therefore, the former system is being used in the routine operation in spite of its drawback.

The main parameters of UVSOR storage ring are tabulated in Table I. The symbols of the parameters in the table are used hereafter without further definition.

Observation of Longitudinal Coupled-Bunch Instability

We built a phase oscillation detector which processes a signal from a button-type fast intensity monitor in order to observe the instability and to determine the coupled-bunch mode number. A block diagram of the detector is shown in Fig.1. A beam signal corresponding to a certain bucket is selected with a gate circuit controlled by a bucket identifier. The phase difference between the signal and the RF acceleration voltage is detected with a double balanced mixer (DBM) and a low-pass filter. At least two circuits are necessary to determine a coupled-bunch mode number. According to the observation, the phase difference between oscillations of two adjacent bunches were always changing, therefore, the mode number was not determined. The fluctuation of the amplitude of the phase oscillation was also observed. Figure 2 shows an example of the fluctuations detected with phase oscillation detectors in a longitudinal feedback system described in the next section; the 4 traces are envelopes of the phase oscillations of the bunches. It is noteworthy that the amplitudes are in no way constant and nodes for the 4 bunches do not occur at the same time. The typical value of the period of the change in amplitude is several ten ms. The following results were obtained in the observations.

1. The threshold current of the instability is about 5 mA at 600 MeV.
2. The average amplitude of the phase oscillation due to the instability is about 0.06 rad at the beam current of 80 mA.
3. Higher-order-mode resonances related to the instability and the coupled-bunch mode number were not specified.

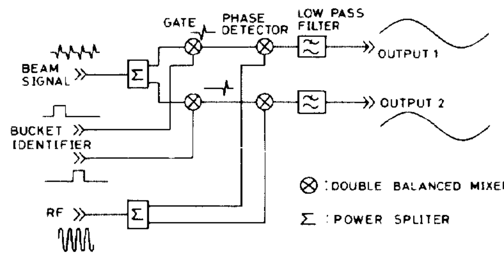

Fig.1 Block diagram of the phase oscillation detector.

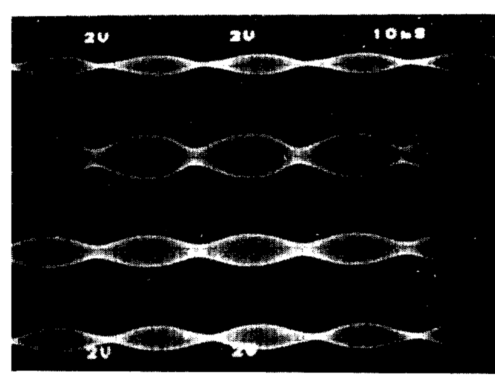

Fig. 2 Fluctuations of the phase oscillation amplitudes of 4 bunches. (10 ms/div.)

TABLE I

Energy	E	600-750 MeV
Mean radius	R	8.47 m
Circunference	$C(=2\pi R)$	53.2 m
Bending radius	ρ	2.2 m
Revolution frequency	f_{rev}	5.63 MHz
Radio frequency	f_{rf}	90.1 MHz
Harmonic number	h	16
Momentum compaction factor	α_p	0.026
Peak RF voltage	V_0	75 kV
Synchrotron frequency	f_s	16-14 KHz

Feedback Method

The longitudinal feedback systems are operated in the CERN PS booster, the NSLS VUV ring and the CERN ISR [1-3]. The former two systems introduce an artificial coupling impedance which simultaneously damps the oscillations of all bunches in a certain mode of the instability. This method is adequate when only a few modes are concerned with the instability. In the last system, each of all bunches is stabilized separately with the independent feedback loop; the energy deviation of each bunch is detected individually and corrected through a wideband RF acceleration system. We adopted a method similar to the latter since the modes of the instability are not unique and changeable as stated above [4].

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A block diagram of the system is shown in Fig.3. The phase oscillation of each bunch is detected by a phase detector similar to the circuit described in the preceding section. After the phase of the output signal is shifted to indicate the energy deviation of the bunch and gated so as not to affect other bunches. All the signals are combined again and modulate the RF signal. Because the spectral bandwidth of the feedback signal is wide, a wideband power amplifier and a acceleration system are essential. A wideband acceleration gap which is a coaxial transmission line with two gaps at both ends was developed (Fig.4). Since one end is terminated with a matched load, the system is essentially wideband.

Suppression of the instability is shown in Fig.5. The upper, middle and lower traces in the figure show the feedback signal applied to the acceleration gap, the envelope of the phase oscillation and the control signal of the feedback loop (high: feedback on, low: feedback off). The rise time of 10 ms and the system damping time of 5 ms are obtained.

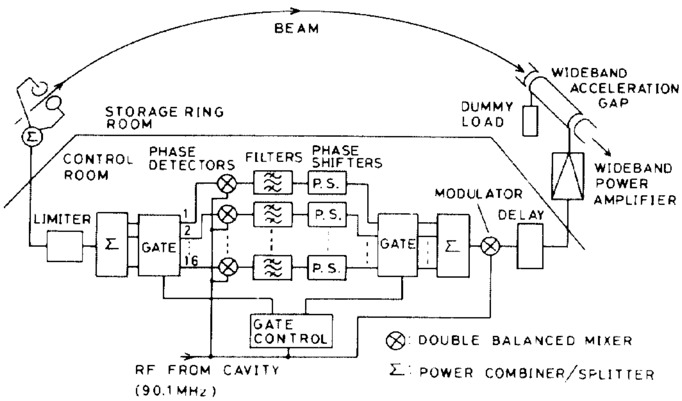


Fig. 3 Block diagram of a direct feedback system.

Decoupling Method

Two kinds of passive damping system for longitudinal instabilities have been reported: Landau cavity or harmonic cavity method and a decoupling method [5-7]. The former makes use of the Landau damping by the spread of the synchrotron frequency due to the strong nonlinearity introduced into the effective acceleration voltage around the stable phase angle. In the latter method, the phase oscillation of individual bunches are decoupled by a spread in their synchrotron frequencies, which is induced externally by modulation of the acceleration voltage. We adopted the latter because the required RF voltage is much smaller than that of the former, and the wideband acceleration gap for the feedback system described in the preceding section was easy to convert to the cavity for the present purpose [8].

Since the bandwidth of the main acceleration cavity is narrow, it is impossible to modulate the cavity voltage directly. We used a sideband acceleration system, the frequency of which differed from that the main cavity by the revolution frequency, in order to modulate the acceleration voltage equivalently. A block diagram of the decoupling system is shown in Fig.6. The radio frequency of the main acceleration system and the revolution frequency are mixed by means of a double balanced mixer, then only the upper sideband $(h+1)f_{rev}$ is amplified and fed to the cavity, which was the wideband acceleration gap for the feedback system (Fig.4). The distance between two gaps which corresponds to a quarter wavelength of the main RF is slightly longer than that of the upper sideband.

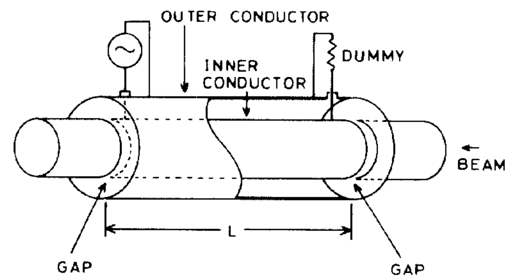


Fig. 4 Wideband acceleration gap.

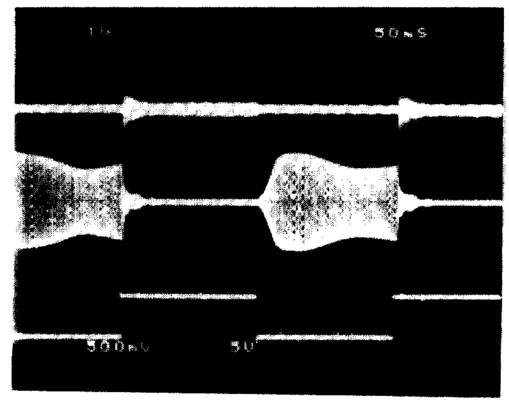


Fig. 5 Effect of feedback. Upper trace: voltage applied to acceleration gap, middle trace: envelope of phase oscillation and lower trace: switching signal for feedback loop. (50 ms/div.)

Therefore matching box and cable are connected to the gap in order to have the system resonate at the upper sideband. A DC voltage is superposed on the RF to avoid the multipactoring effect. The cavity was excited by a power amplifier with the output power of 100W. The acceleration voltage is monitored with a capacitive divider at the open circuited end of the cavity. The effective acceleration voltage V_a is 1.1 times as large as the monitored voltage, considering the beam is also accelerated at the feeding side.

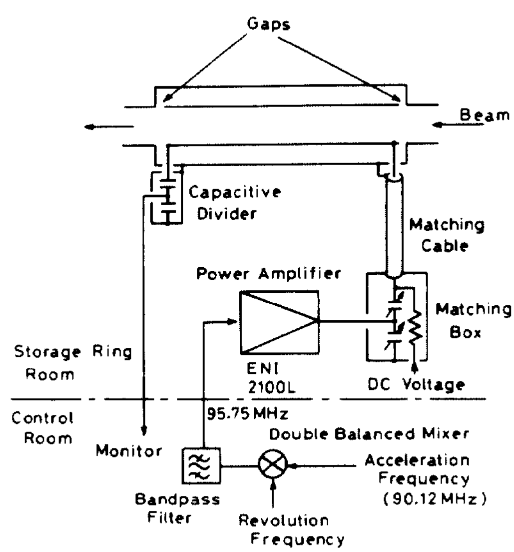
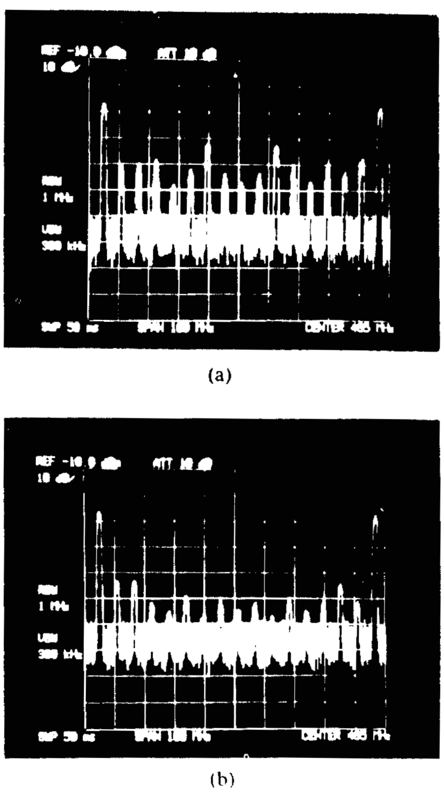


Fig. 6 A block diagram of the longitudinal passive damper.

The spread in the synchrotron frequencies was measured with a spectrum analyzer, which analyzed the synchrotron oscillation excited externally by the frequency modulation of the main acceleration voltage. A spectrum of a signal from a button-type fast intensity monitor was also observed with a spectrum analyzer to detect the instability. Photographs (a) and (b) in Fig.7 show spectra without and with the damper, respectively. The two lines at either end show harmonics of the main RF and fifteen lines in between corresponding to the synchrotron oscillation due to the instability are suppressed with the damper. (The residual lines in photograph (b) result from lack of uniformity in bunch populations.)

The threshold current above which the instability starts was measured as a function of the beam energy E and the voltage of the main and sideband acceleration systems (V, V_a). The results are shown in Fig.8. As seen in Fig.8, the threshold current determined by the balance of the instability and the radiation damping is 40mA at a beam energy of 750 MeV. The threshold current increases up to 80 mA when the voltage V_a of the sideband cavity is 0.9 kV.

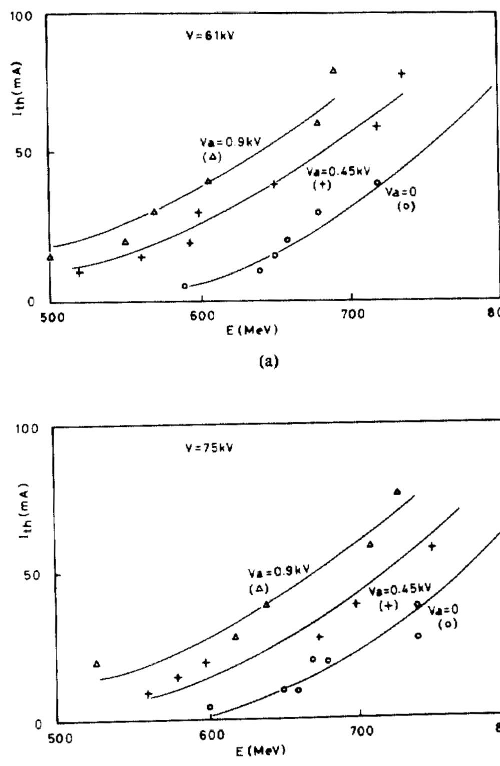
The longitudinal coupled-bunch instability in the UVSOR storage ring can be suppressed with the decoupling method. Since the shunt impedance of the sideband cavity including the matching box and cable was too low (6.6kΩ) in the experiment, the acceleration voltage of the sideband cavity was not sufficient to suppress the instability at the high beam current ($\sim$100 mA). If we use the cavity with the shunt impedance of 50 kΩ, the instability at 100 mA 600 MeV can be suppressed by a RF power amplifier with an RF power of 100 W. This method offers the benefit that influence of the beam loading is negligible. Namely, no beam loading occurs if individual bunches have the same population. Furthermore, even if the loading due to a spread in population occurs, it is not necessary to control the phase of the acceleration voltage of the sideband cavity because the phase difference between two cavities may be arbitrary.



(a)

(b)

Fig. 7 Spectra of a signal from a fast intensity monitor. (a) Damper off. (b) Damper on.



(a)

(b)

Fig. 8 The threshold current as a function of beam energy and acceleration voltage of the sideband system. The main acceleration voltage of 61kV (a) and 75kV (b).

Conclusions

The threshold current of the longitudinal coupled-bunch instability induced by the higher-order-mode resonances of the acceleration cavity is 5 mA at the beam energy of 600 MeV. The instability can be suppressed by a feedback method or a decoupling method. The adjustment-free characteristic is an advantage of the decoupling method. However, the maximum instability suppressible current with the system is only 80 mA at 750 MeV up to now, since we have no proper cavity for the system. In the routine operation, we use the feedback system to suppress the instability.

References

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