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SUPPRESSION OF LONGITUDINAL COUPLED BUNCH INSTABILITIES IN NIJI-II ELECTRON STORAGE RING

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Abstract

The decoupling method with a sideband cavity for suppression of longitudinal coupled bunch instabilities was tried in the NIJI-II electron storage ring at its injection energy of 150MeV. The basis of the method is spreading the synchrotron frequencies of the individual bunches by means of the modulation of the effective acceleration voltage. The instabilities were successfully damped with the method when the beam current was below about 4.5mA. However when the beam current exceeded the value, a longitudinal coupled bunch instability with a certain coupled bunch mode was excited by the sideband cavity itself. In order to suppress the instability, a longitudinal active damping method was also tried. With the system, the energy deviations of all bunches are corrected simultaneously. As a result, the instability was satisfactorily damped when the beam current was about 40mA.

Introdution

NIJI-II is a 600MeV electron storage ring mainly used for photon-induced chemical vapor deposition.[1),2)] In the ring, synchrotron sidebands have been already observed at the beam current of 2mA. In the machine studies, we found that the sidebands were caused by longitudinal coupled bunch instabilities. To suppress the instabilities, we adopted the decoupling method (tune splitting method) with a sideband cavity. The method is one of the passive damping methods, which spreads synchrotron frequencies of individual bunches by means of the modulation of the effective acceleration voltage so as to decouple the synchrotron oscillations of bunches each other. The instabilities were damped with the method when the beam current was less than 4.5mA. However, when the beam current exceeded the value and the growth rate for a certain mode (n=1) exceeded the damping rate by the method, the mode was excited by the sideband cavity itself.

Since the mode of the instability excited by the sideband cavity is determined by its resonant frequency, we adopted a longitudinal active damping system (mode feedback system) which damped only the mode. This system is similar to that developed for the CERN PS booster by F.Pedersen et al.[3),4)] In the system, the phase of the harmonic component corresponding to the mode extracted from the beam pickup signal was shifted by 90°, and fed back to the sideband cavity via a power amplifier. The instability was satisfactorily damped when the beam current was about 10mA. Moreover when the beam current was about 36mA, the amplitude of the phase oscillation was suppressed down to about a third of that without the feedback.

Table I: Main Parameters of NIJI-II

Energy	E	150-600MeV
Circumference	C	17.06m
Revolution frequency	f_{rev}	17.6MHz
Radio frequency	f_{rf}	158.2MHz
Harmonic number	h	9
Momentum compaction factor	α	0.60
Synchrotron frequency (150MeV)	f_s	265kHz
Radiation damping time (150MeV)	τ_x	2.3s
	τ_y	0.53s
	τ_ε	0.19s

The main parameters of NIJI-II storage ring are shown in Table I. The symbols of the parameters in the table are used in the following sections without further definition. Experiments in the following sections were made at the injection energy of 150MeV.

Decoupling method

The growth rate $1/\tau_i$ of longitudinal coupled bunch instabilities due to a resonant element characterized by a shunt impedance R_{sh} and resonant frequency f_{res} is given by

$$\frac{1}{\tau_i} = \mathrm{Im}\left(0.159\frac{R_{sh}\, I\, \omega_s}{V\cos\phi_s}\,\frac{T_0}{\tau_b\, h}\,DF\left(\Delta\phi\right)\right), \qquad (1)$$

where V and ϕ_s are the voltage and the stable phase of the RF acceleration system, I the beam current, T_0 the revolution period, τ_b the bunch length in seconds, ω_s the synchrotron angular frequency, and D the factor that depends on the

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attenuation of the induced signal between bunches. F is the form factor that specifies the efficiency with which the resonator can drive a given mode, and depends on the phase change $\Delta\phi$ during the passage of a bunch: $\Delta\phi = 2\pi f_{\mathrm{res}} \tau_{\mathrm{b}}$.5) The growth rate of the instabilities can be suppressed by the decoupling method, the basic mechanism of which is a spread in the synchrotron frequencies of the individual bunches. Since the synchrotron frequency of a bunch is determined by the gradient of the acceleration voltage $\dot{V}$, the spread can be introduced artificially by modulation of the voltage. However, since the bandwidth of the main RF acceleration cavity is very narrow, it is impossible to modulate the voltage directly. So we adopted a second acceleration system, i.e. a sideband cavity, the resonant frequency of which is $(\mathrm{m}h+1) f_{\mathrm{rev}}$ in order to modulate the effective acceleration voltage, where m is an integer (in our case, m=2). The main parameters of the sideband cavity are shown in Table II.

Table II: Main parameters of the sideband cavity

Resonant frequency	f_{res}	334MHz
Unloaded Q	Q_0	1100
Shunt impedance	R_{sh}	74kΩ

With the system, the peak spread $\Delta\omega_{\mathrm{s}}$ of synchrotron angular frequencies is

$$\Delta\omega_{\mathrm{s}} = \frac{1}{2}\,\omega_{\mathrm{s}}\,\frac{\mathrm{m}h+1}{h}\,\frac{V_{\mathrm{a}}}{V}, \tag{2}$$

where V_{a} is the peak voltage of the second acceleration system. Assuming that the damping rate of this system is proportional to the rms synchrotron angular frequency spread, we obtain the effective growth rate $1/\tau$ becomes

$$\frac{1}{\tau} = \frac{1}{\tau_{\mathrm{i}}} - \frac{\delta\omega_{\mathrm{s}}}{a}, \tag{3}$$

where a is a constant.6) We ignore the radiation damping rate because it is very small compared with the damping rate of the system.

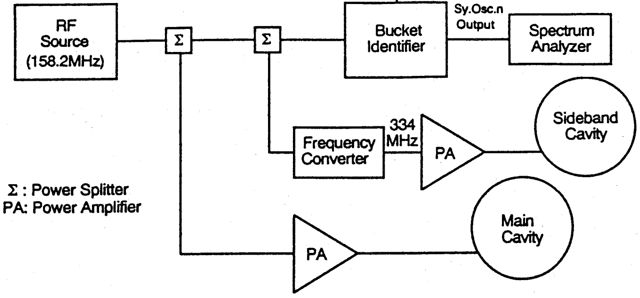


Figure 1: The decoupling system.

A block diagram of the decoupling system is shown in Fig.1. The RF signal (158.2MHz) is splitted into two systems. One is amplified and fed to the main cavity, the other is frequency converted to 334MHz and fed to a sideband cavity via a power amplifier (THAMWAY A50-7801, output power 100W).

To test the effectiveness of the system, the synchrotron frequencies of all bunches were measured independently with a spectrum analyzer. Since the beam pickup signal contains information of all bunches, we used a bucket identifier which selected the signal corresponding to a certain bunch from the beam pickup signal. An example of results of the measurement is shown in Fig.2. The solid curve in the figure shows a fitted result by the least square method using a computer code MINUIT. The spread is consistent with the estimation from the monitored acceleration voltage of the sideband cavity. A spectrum of the beam signal was also observed with a spectrum analyzer to find the current at which the instabilities could not be suppressed with the method any more. As a result of the observation, we estimated the current at about 4.5mA when the peak voltage V_{a} of the sideband cavity was 2.9kV$_{\mathrm{p\text{-}0}}$. Then we obtained the empirical value $a \approx 7$ from eq.(3).

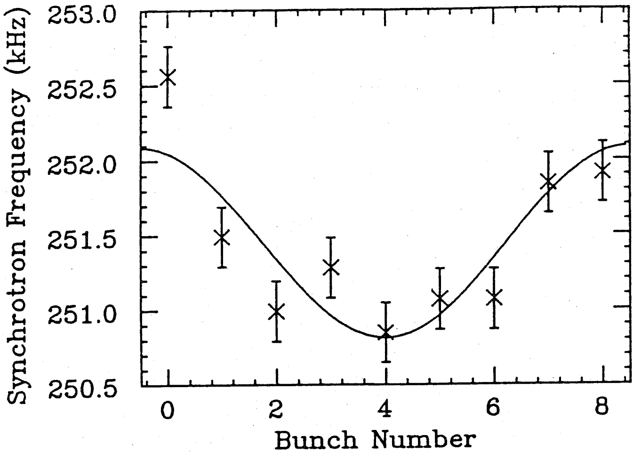


Figure 2: Synchrotron frequencies of bunches. Maximum spread was about 1.1kHz. The expected spread is 1kHz.

Mode feedback method

The beam spectrum lines due to a longitudinal coupled bunch instability with a coupled bunch mode number n appear at the frequencies $khf_{\mathrm{rev}} \pm (nf_{\mathrm{rev}} + f_{\mathrm{s}})$, where k is an integer. In the mode feedback system, the harmonic component that corresponds to the coupled bunch mode n is filtered out from the beam pickup signal, and fed back to a cavity after its phase is shifted by 90° with respect to the phase of the phase oscillation of the beam. The energy deviation of all bunches is corrected simultaneously. In our case, since it was possible to convert the sideband cavity for the decoupling method into the cavity for the feedback system, we chose the components around 334MHz (k=2).

A block diagram of the system is shown in Fig.3. The system consists of a feedback filter, a feedback controller, a variable delay, a power amplifier and the sideband cavity (feedback cavity). Fig.4 shows a block diagram of the feedback filter and the feedback controller. The filter consists of two band-pass filters and four double balanced mixers(DBM). The center frequency of the band-pass filter covers the range from 130kHz to 900kHz, because the synchrotron frequency changes

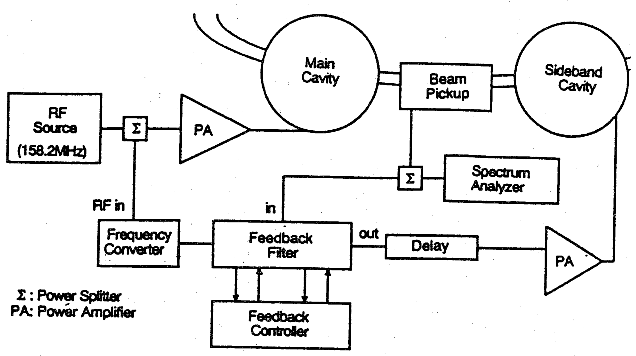


Figure 3: The mode feedback system.

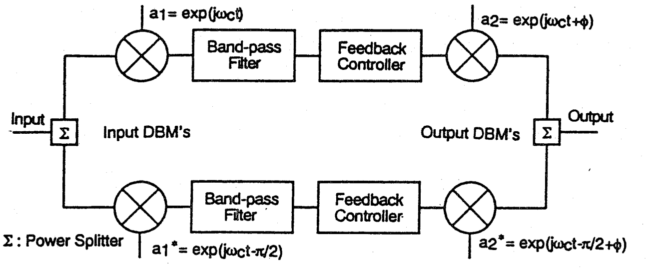
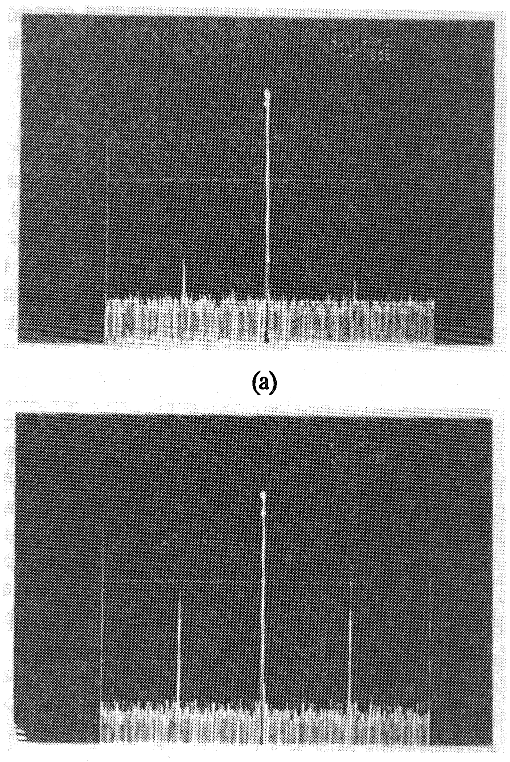


Figure 4: A block diagram of the feedback filter and the feedback controller.



(a)

(b)

Figure 5: Spectra of a beam pickup signal. (a) Feedback on, beam current 10mA. (b) Feedback off, 10mA. Lines at both ends are synchrotron sidebands. (Center frequency=334MHz, Span 1MHz)

according to the acceleration voltage or the operating energy. The beam pickup signal is splitted into two channels, and mixed with a pair of radio frequency (f_c=334MHz) signals (a_1,a_1^*), which are in quadrature each other, by means of the first DBM's. Output signals of the first DBM's pass through the band-pass filters and the feedback controllers in each channel, and combined again after being mixed with a pair of 334MHz signals in quadrature (a_2,a_2^*). The feedback controller is used to control the phase and the level of the band-pass filter output. Using them, the undesired components are eliminated and only the components of f_c+f_s and f_c-f_s appear at the output. The output signal of the feedback filter is delayed by the variable delay, amplified and fed to the sideband cavity.

Results of the method are shown in Fig.5. Photographs (a) and (b) in Fig.5 show spectra with and without the damper, respectively. It is shown that the instability was satisfactorily suppressed by the method: the amplitude due to the instability was damped down to about 1/10 (-20dB) when the beam current was 10mA. When the beam current was 36mA, the amplitude due to the instability was damped down to about 1/3 (-10dB). At that time, since the sideband cavity was detuned so that the instability was damped, we could not supply the sufficient power to damp the instability completely into the sideband cavity satisfactorily.

Summary

We tried the suppression of the longitudinal coupled bunch instabilities by the decoupling (tune splitting) method with a sideband cavity in the NIJI-II electron storage ring. Though the instabilities was perfectly suppressed by the method when the beam current was below 4.5mA, a longitudinal coupled bunch instability with a coupled bunch mode number n=1 was excited by the sideband cavity when the beam current exceeded 4.5mA. We adopted the mode feedback system to suppress the instability because the mode of the instability was uniquely determined from the resonant frequency of the sideband cavity. With the system, the amplitude of the phase oscillation due to the instability was damped down to 1/3 when the beam current was 36mA. In the future, we will try simultaneous use of these two methods to suppress the instabilities, and also want to investigate the energy dependence of the instabilities and the effectiveness of the same system at the maximum energy of 600MeV.

References

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