BEAM INSTABILITIES IN THE PF STORAGE RING

H. Kobayakawa, M. Izawa, Y. Kamiya, M. Kihara and Y. Yamazaki

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

ABSTRACT

Unstable regions for three coupled-bunch instabilities were studied. Two destructive instabilities can be avoided by choosing properly the cooling water temperature for the RF cavities. Trapped ions cause a vertical beam instability which can be suppressed by applying RF knock-out field or phase modulation of the accelerating field to the beam.

INTRODUCTION

In the Photon Factory, the operating energy is 2.5 GeV and the storage ring is routinely stored with the beam of 150 mA in the multi-bunch mode at the present user time. A vertical wiggler with 3 pole superconducting magnets and an undulator having 60 permanent magnet poles are operating regularly with a long beam lifetime of typically 10 hrs at 150 mA. Parameters of the PF storage ring and the RF acceleration system are summarized in Table 1.

Experiments with synchrotron radiation require stability of the stored beam. Therefore, properties of the beam instabilities have been studied extensively to find out method of suppressing them. Observed instabilities are classified into two groups; (1) coupled-bunch instabilities[1,2] which all arise from the high coupling impedances of the accelerating cavities, (2) vertical instability[3] which is probably caused by the effect of positive ions trapped in the electron beam orbit.

COUPLED-BUNCH INSTABILITIES

Three coupled-bunch instabilities have been observed. Because they are all caused by the cavity impedances, damping antennae[4] can suppress them. Careful tests for the damping antenna are progressing with high RF power using a test cavity, before installation into the operating cavities.

The observed coupled-bunch instabilities are summarized in Table 2, where the related cavity modes, frequencies, and the modes of coupled-bunch oscillation are included. Problems due to them are also presented.

Two horizontal instabilities, "1070"[1] and "830", are very destructive and lead to beam loss. Accumulation of beams is limited at a certain stored current, therefore we must eliminate them. The longitudinal instability "758"[2] accompanies with beam size modulation whose frequency is about 200 Hz. This modulation can be seen in a horizontal beam profile monitor which is a photo-diode array on which synchrotron light is projected. Sometimes it causes the beam lifetime to decrease especially during the operation of the vertical wiggler, whose beam pipe is narrow (3 cm) horizontally.

Temperature dependence of the unstable regions

Cavity temperature can be given by the values of power dissipated in the cavity, P_c, and temperature of cooling water, T_w. The frequency shift of the accelerating mode due to temperature change can be canceled correctly by the tuning plunger. However, the frequencies of the higher order mode resonances cannot be corrected. As a result, the unstable regions of the cavity caused instabilities move with the cavity temperature. We measured the unstable regions with the parameters of P_c and T_w. Figure 1 shows the unstable region of "758" measured by varying the accelerating frequency f_{RF}. Unstable regions of "1070" and "830"

Table 1

Parameters of RF system

RF frequency	500.105 MHz
Revolution frequency	1.60290 MHz
Harmonic number	312
Number of bunches	312
Momentum compaction factor	0.040
Synchrotron radiation loss	0.51 MV (6 T)
Power dissipated in cavities	116 kW
Cavity gap voltage	1.9 MV
Shunt impedance (four cavities)	33 MΩ
Unloaded Q-value of the fundamental mode	37,000
Quantum lifetime	4 days
Synchronous phase	77°
Bunch length	79 ps
Synchrotron frequency	58 kHz
Field of vertical wiggler	6 T
Number of RF stations	2
Number of klystrons	2
Number of RF cavities	4

Table 2

Summary of coupled-bunch instabilities. Observed resonant frequencies, Q-values and coupling impedances of the RF cavity are presented. Units of impedances are MΩ and MΩ/m for TM0 and TM1 modes, respectively.

Cavity mode		frequency (MHz)	$Q_{exp.}$	R (MΩ or MΩ/m)	Mode* of coupled-bunch	Instability	Problems**
"758"	TM011-like	758	19,000	3.02	161	Longitudinal	short lifetime
"1070"	TM111-like	1070	21,000	27±1	268	Horizontal	H, BL
"830"	TM110-like	829	29,000	12±1	103	Horizontal	H, BL

* Definitions are given in Ref. 1 and 2.
** H: Beam oscillates horizontally.
BL: Beam loss.

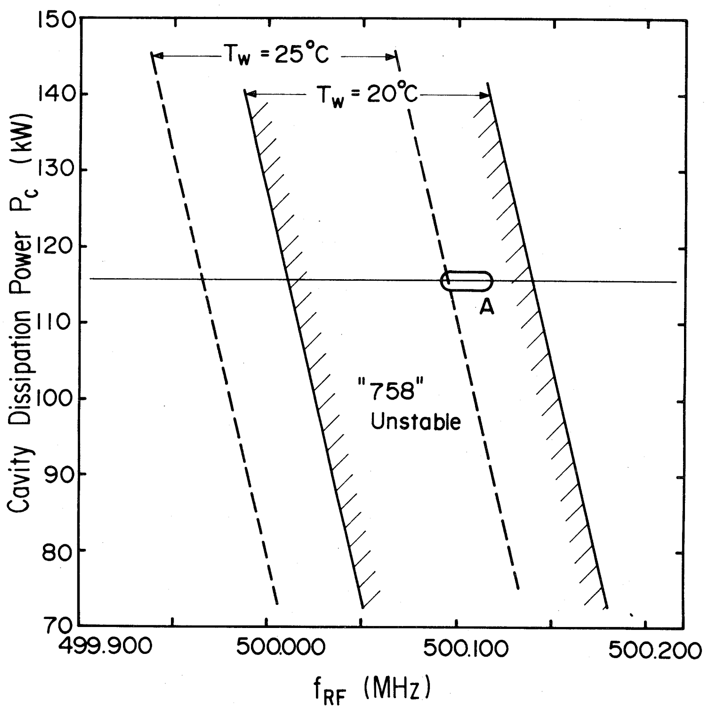

Fig. 1 Unstable region of the longitudinal coupled-bunch instability "758". Outside of this area, the beam is stable at least up to 70 mA. Measurement was performed by varing the accelerating frequency f_{RF} and temperature parameters P_c and T_w. Mark "A" is the operating point.

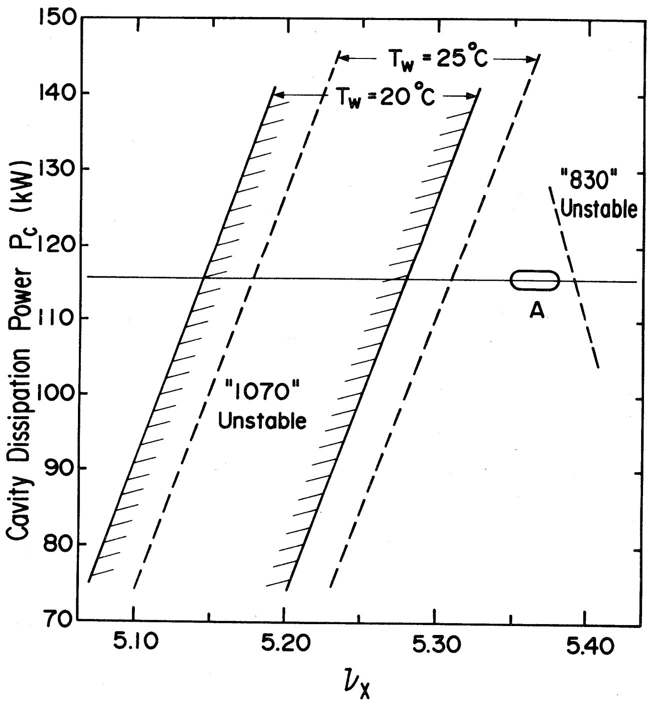

Fig. 2 Unstable region of the horizontal coupled-bunch instabilities, "1070" and "830". Temperature effect can be seen with two parameters P_c and T_w. Horizontal axis is the horizontal betatron tune ν_x and "A" is the operating point. RF accelerating frequency was 500.105 MHz.

are given in Fig. 2 as a function of the horizontal betatron tune ν_x. For the operation of the vertical wiggler, P_c is set at 116 kW for the quantum lifetime of 4 days. Thus the operating region is on a horizontal line indicated in the figures. As mentioned previously two transverse instabilities must be avoided. Present temperature regulation system for the cooling water is limited in the temperature range from 20° to 30°C with errors of ±1°C. Moreover, temperature setting cannot be made for each cavity. With this regulation system, operation at higher temperature than 25°C is difficult, because both transverse instabilities come closer to the operating point. Therefore present operating temperature T_w is set at 20°C and the horizontal betatron tune is chosen to be 5.35 to 5.38 as indicated as "A" in Fig. 2. However, the instability "758" cannot be eliminated under this condition.

Longitudinal instability "758" and its reduction

We have two RF stations on the north and south side of the storage ring. Each station contains a klystron and two accelerating cavities. Phase difference ϕ_{AB} defined as $\phi_{AB} = \phi_B - \phi_A$, where ϕ_A is the phase of the accelerating field of the north station and ϕ_B is that of the south station, should normally be kept nearly zero. If ϕ_{AB} is given a non-zero value which is not large, difference of the beam loading power between two stations increases. The cavity dissipation power P_c of each cavity increases or decreases depending on the its phase relation. Thus, we can give proper power P_c by adjusting ϕ_{AB}. Figure 3 is an example of the resonant frequency shift by this procedure and Fig. 4 is presenting the "758" modulation become large or small by ϕ_{AB}.

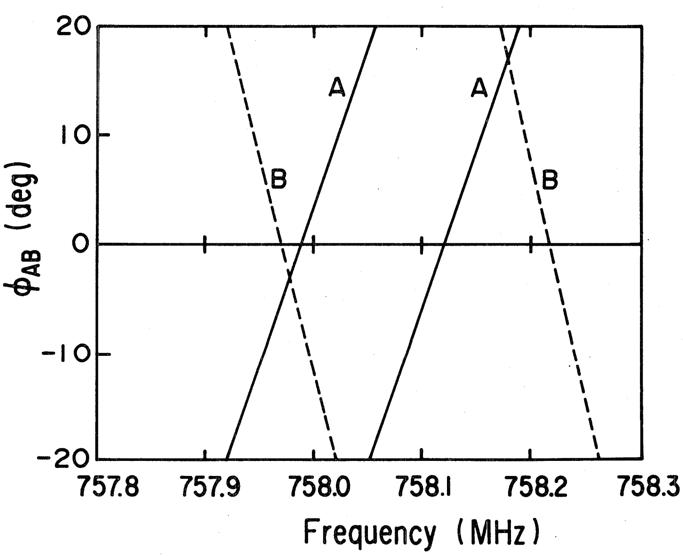

Fig. 3 Estimated frequency shifts of TM011-like mode resonance due to the phase difference ϕ_{AB} between two RF stations. Beam current is 100 mA and effect of the detuning are taken into account. A and B correspond to the cavities of the south and north stations, respectively.

VERTICAL INSTABILITY

In the uniformly filled mode, the vertical instability[3], although it leads to no beam loss, appeared as a regular spikes in the vertical profile monitor. It is not the coupled-bunch instability. In the partially filled mode, the beam blows up irregularly and sometimes leads to beam loss both in the injection

(a)

(b)

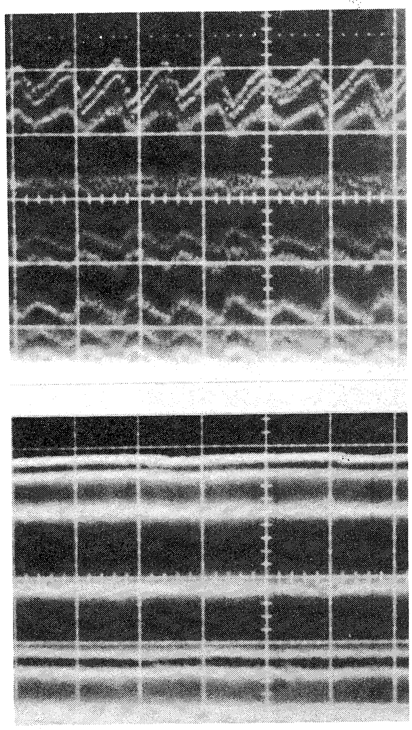

Fig. 4 Horizontal beam profiles in the scan width of 10 ms/division. (a) ϕ_{AB} = 18°. Beam size modulation was large. Stored current was 100 mA. (b) ϕ_{AB} = -20°. The beam was quiet.

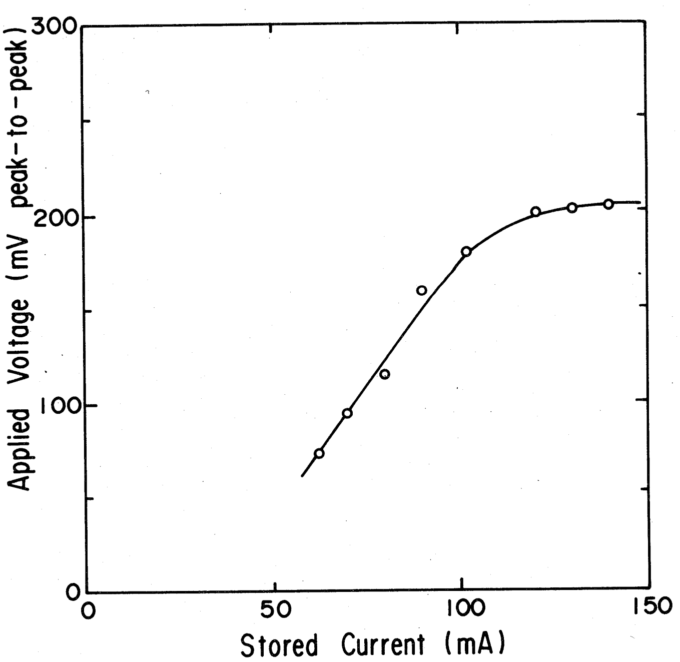

Fig. 5 Stored current dependence of externally applied voltage V_{pp} for the phase modulation, above which vertical instability stops. Frequency of the phase modulation was 56 kHz.

and storage time. These phenomena can be reduced by excitation of the defocusing sextupole magnet. However, in the violent case, it disturbs the machine operation and the synchrotron radiation experiments.

Some phenomena related to this instability are not necessarily reproducible. Moreover, strange behaviour depending on the vertical betatron tune is observed. However, we have several evidences that it clearly correlates to the vacuum condition in the beam chamber. The most likely interpletation for these phenomena is that the ion-trapping gives rise to the instability.

Methods of cure

(1) Vertical instability can be suppressed by applying the RF knock-out field of which frequency is 1.3 MHz whichever horizontal or vertical directions. Details of this technique will be described elsewhere[5].

(2) By applying external phase modulation on the RF accelerating field, the vertical instability can be stopped. Frequency of the external force is slightly below the synchrotron frequency f_s. External voltage is given on a electrical phase shifter which is located right after the master oscillator. Amplitude of the applied voltage V_{pp}, where the vertical blow-up stops, are plotted against the stored beam current in Fig. 5. Voltage V_{pp} of 100 mV at frequency of 56 kHz produces small phase modulation of 0.5 % in the cavities. This external force enlarges the bunch length by 50 % and, as a result, the beam size increases horizontally by 20 %.

CONCLUSIONS

Unstable regions of three cavity induced instabilities were studied extensively. Dependence on the cavity temperature was measured with parameters of P_c and T_w. Two transverse coupled-bunch instabilities should be kept away from the operating region, because they cause a lot of trouble on the machine operation. Water cooling system for the cavities should have the function of temperature regulation for each cavity. However in limitation of present control system, the best set of water temperature is 20°C. The longitudinal instability can be reduced its effect by adjusting ϕ_{AB}.

The vertical instability, of which mechanism is not clear yet, is suppressed by applying external forces; the RF knock-out field of 1.3 MHz or the phase modulation on the RF accelerating field whose modulation frequency is slightly lower than the synchrotron frequency.

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REFERENCES

1. Y. Yamazaki, H. Kobayakawa, Y. Kamiya and M. Kihara: KEK Report KEK-83-3, 1983.
2. Y. Yamazaki, H. Kobayakawa, Y. Kamiya and M. Kihara: KEK Report KEK-83-7, 1983.
3. Y. Yamazaki, M. Kihara and H. Kobayakawa: KEK Report KEK 83-17, 1983.
4. Y. Yamazaki, K. Takata and S. Tokumoto: KEK Report KEK 80-8, 1980.
5. Y. Kamiya, M. Izawa, T. Katsura, M. Kihara, H. Kobayakawa, S. Shibata: to be published in the Proceedings of this conference.