Particle Accelerators, 1990, Vol. 33, pp. 93–98
Reprints available directly from the publisher
Photocopying permitted by license only

MEASUREMENT OF TRANSVERSE INSTABILITY THRESHOLDS IN LOW AND HIGH EMITTANCE OPTICS AT THE PHOTON FACTORY STORAGE RING

SHYOGO SAKANAKA, MASAAKI IZAWA, YUKIHIDE KAMIYA,
MASAHIRO KATOH AND HISASHI KOBAYAKAWA
Photon Factory, National Laboratory for High Energy Physics
Oho, Tsukuba-shi, Ibaraki-ken, 305 Japan

Abstract A horizontal coupled-bunch instability was experimentally studied in low and high emittance optics at the Photon Factory storage ring. Threshold currents were measured by changing excitation currents of octupole magnets for both optics. The result and discussion are presented.

INTRODUCTION

The Photon Factory storage ring (PF ring) is a 2.5 GeV electron/positron storage ring dedicated to the synchrotron radiation researches at KEK.[1] There are four single-cell cavities in the PF ring for acceleration with a frequency of 500.1 MHz. We have observed five coupled-bunch instabilities arising from higher-order mode resonances of the cavities;[2-4] TM011- and TM013-like modes for the longitudinal instabilities, and TM110(H)- and TM111(H,V)-like modes for the transverse instabilities.

At the end of FY1986, a low emittance optics of the PF ring was brought into operation in order to improve brilliance of the synchrotron radiation.[5] Parameters in the low and high emittance optics are presented in Table I and Fig. 1. It was found that the coupled-bunch instabilities became large in the low emittance mode. In this report, we focus on the horizontal coupled-bunch instability caused by the TM111-like mode resonance.

MEASUREMENT OF THRESHOLD CURRENTS

Transverse coupled-bunch instability can arise if a resonant frequency f_{res} of a transverse deflecting mode in cavities coincides with one of the beam modes:[6]

$$f_{res} = f_{\mu,n}^{-} = nBf_r - \mu f_r - f_\beta \ , \qquad (1)$$

TABLE I Parameters of the low-emittance and the high-emittance optics.

		High-emittance	Low-emittance
Horizontal tune	ν_x	5.40	8.38
Vertical tune	ν_y	4.16	3.14
Momentum compaction factor	α	0.037	0.015
Horizontal natural chromaticity1)	ξ_x	-6.8	-15.8
Vertical natural chromaticity1)	ξ_y	-4.7	-8.6
Horizontal damping time	τ_x (msec)	7.8	7.8
Vertical damping time	τ_y (msec)	7.8	7.8
Horizontal emittance	ε_x (nm·rad)	404	127
Vertical emittance	ε_y (nm·rad)	~6	~2
Bunch length	σ_z (cm)	2.1	1.3

1) defined by $\Delta\nu/(\Delta p/p)$.

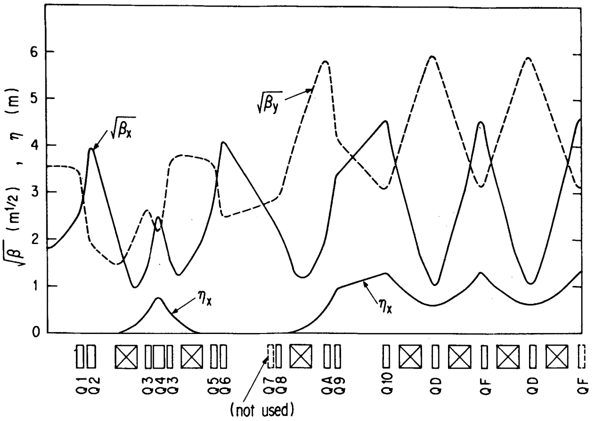
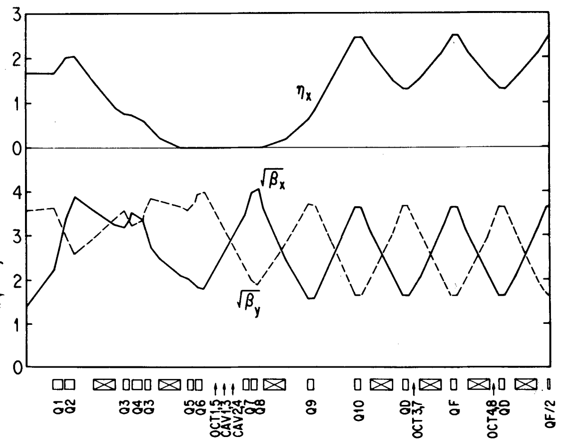


FIGURE 1 Betatron- and dispersion functions in one quadrant.

(a) Low emittance optics.



(b) High emittance optics.

where n is zero or positive integer, B the number of bunches (=312), μ the mode number of the coupled-bunch oscillation, f_r the revolution frequency (=1.6029 MHz), and f_β the fractional betatron frequency ($=\delta\nu f_r$). In case of the horizontal instability due to TM111-like mode, we have f_{res} = 1070.28 MHz, n=3 and μ=268. A threshold current is defined as a beam current when the frequency component of eq. (1) appears in a frequency spectrum during beam injection. Here, beam signal was taken from a button-type position monitor.

We measured at first the threshold currents by changing the horizontal betatron frequencies for the both optics. The result is shown in Fig. 2. Data were taken at cavity dissipation powers (P_C) of 29 kW/cavity with cooling water temperatures of (20,20,18,20)°C for the cavities #1 to #4. The measurement was made with electron beam. Figure 2 shows that the threshold currents in the low emittance mode became lower by factors of 4 to 7 than in the high emittance mode. Numbers 1 to 4 in the figure represent the cavity dominantly contributing to the instability, which was identified by changing the temperatures of cavity cooling water.

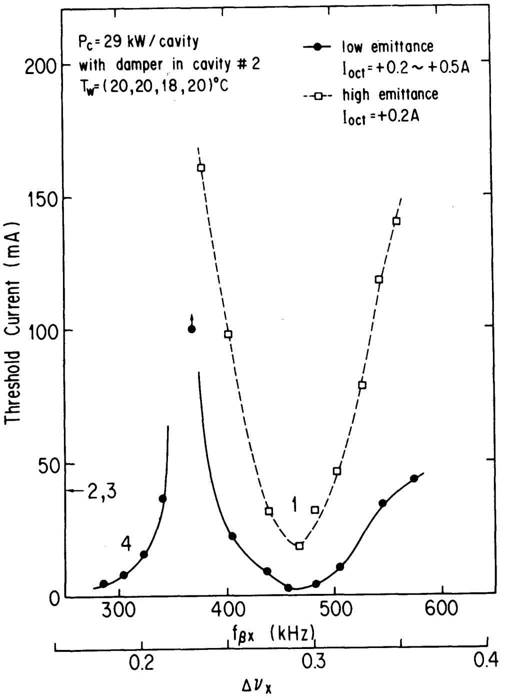


FIGURE 2 Threshold currents of the horizontal coupled-bunch instability caused by the TM111-like mode versus horizontal tune. Numbers 1 to 4 represent the cavity numbers.

Octupole magnets in the PF ring provide for a betatron frequency spread and thereby suppressing the transverse instabilities by the Landau damping. The threshold currents of the horizontal instability were measured by changing excitation currents of the octupoles for the both optics. Six octupole magnets were used in this experiment. The strength was B'''l/Bρ $[\mathrm{m}^{-3}] = 72.4 \times I_{oct}[\mathrm{A}]$ per magnet. The horizontal betatron frequency (fractional) was set to 454kHz which gave the lowest thresholds for the both optics (Fig. 2). All cavity conditions such as dissipated rf power and temperatures of cooling water were kept constant during the measurement.

Figure 3 shows the experimental data which leads to following results. (1) Octupole currents which gave minimum thresholds were not zero and different between the two optics. It suggests an existence of octupole components in the guide fields, strengths of which were different in two optics. (2) The minimum values of the threshold were 2.6 mA (low-ε) and 5.5 mA (high-ε), respectively. (3) Octupole dependences $\Delta I_{th}/\Delta I_{oct}$ were ~9 mA/A (low-ε) and ~14 mA/A (high-ε), respectively.

DISCUSSION

A simplified criterion for the coupled-bunch instability is that the instability arises if a growth rate exceeds damping rate τ_β^{-1}. Then the threshold current is given by[2,7]

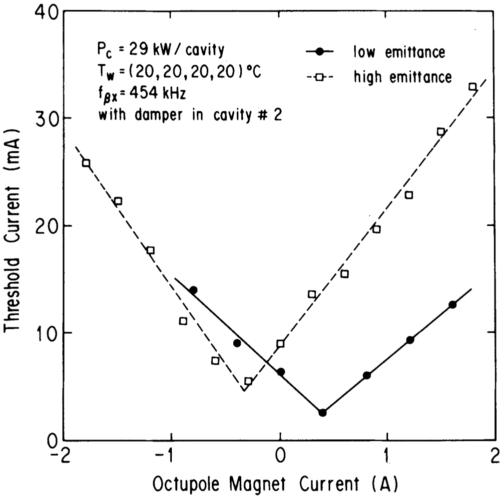


FIGURE 3 Threshold currents of the horizontal coupled-bunch instability versus excitation current of octupole magnets. Data were taken for both optics with the same cavity conditions.

$$I_{th} = \frac{2E\tau_\beta^{-1}}{e f_r \beta_\perp \mathrm{Re} Z_\perp(\omega_{\mu,n}^{-}) F'(\chi - \omega_{\mu,n}^{-}\tau_L)} , \qquad (2)$$

where E is the beam energy, $\beta_\perp$ the betatron function at the cavity, F' the form factor defined by Sacherer, $Z_\perp$ the transverse coupling impedance, τ_L the full bunch length, $\omega_{\mu,n}^{-} = 2\pi f_{\mu,n}^{-}$, and $\chi = 2\pi\xi f_r \tau_L/\alpha$.

In presence of the octupole field, betatron frequencies depend on the amplitudes of betatron oscillation, which leads to the Landau damping.[7-9] Then the damping rate is approximately given by

$$\tau_\beta^{-1} \sim \tau_{rad}^{-1} + \omega_r |\Delta\nu_x| , \qquad (3)$$

where τ_{rad} is the radiation damping time, $\omega_r = 2\pi f_r$, and $\Delta\nu_x$ is the full-spread at half height of the horizontal tune distribution. Using an averaging method,[10] $\Delta\nu_x$ is approximately given by

$$\Delta\nu_x \sim \frac{1.18}{16\pi} \Sigma \frac{B'''l}{B\rho} (\beta_x^2 \varepsilon_x - 2\beta_x\beta_y\varepsilon_y) , \qquad (4)$$

where $\beta_{x,y}$ are the betatron functions at the location of the octupole magnets, $\varepsilon_{x,y}$ are the beam emittances, and the sum is taken over all octupoles. Using calculated values for $\beta_{x,y}$, we have $\Delta\nu_x = 7.0\times10^{-5}\times I_{oct}[A]$ and $\Delta\nu_x = 6.0\times 10^{-5}\times I_{oct}[A]$ for the low and high emittance optics, respectively. In the low emittance optics, we have large β_x at the octupoles which cancelled the reduction of $\varepsilon_{x,y}$ to give the same order of $\Delta\nu_x$ as that in the high emittance optics.

At the measurement of the octupole dependences, $f_{\beta x}$ was set to 454 kHz, at which $\omega_{268,3}^{-}$ was nearly equal to ω_1, the resonant angular frequency of the TM111-like mode of the cavity #1. Since the other cavities did not contribute to the instability, we can approximate that $Z_\perp(\omega_{268,3}^{-}) \sim R_\perp \sim 27$ MΩ/m, where $R_\perp$ is a coupling impedance of TM111-like mode of the cavity #1. Using following values; E = 2.5 GeV, $F'(\chi - \omega_{268,3}^{-}\tau_L) \sim 0.8$, $\tau_{rad} = 7.8$ msec, and $\beta_\perp = 10.6$ m (low-ε) and 6.6 m (high-ε), respectively, the threshold currents are written by

$$I_{th} \sim a |I_{oct}| + I_{min} , \qquad (5)$$

where I_{min} ~ 1.7 mA with a ~ 10mA/A for the low emittance optics, and I_{min} ~ 2.8 mA with a ~ 13 mA/A for the high emittance optics, respectively. The calculated I_{min}'s are smaller than the experimental values. But a ratio $(I_{min})_{low-\varepsilon}/(I_{min})_{high-\varepsilon}$ is ~0.6, which is close to the experimental result of ~0.47. The increase of the instability in the low emittance optics can qualitatively be understood in terms of the larger betatron function at the location of the cavity. The calculated a's in eq. (5) are in good agreement with the experimental result.

In a routine operation, the horizontal instability, together with other coupled-bunch instabilities, has been avoided by careful frequency adjustments of the higher-order modes.[4]

CONCLUSION

The threshold currents of the TM111-like mode instability were measured for the low and high emittance optics by changing the octupole currents. In the low emittance optics, the minimum value of the threshold decreased by a factor of two. This can be understood by the increase of the betatron function at the cavity. The octupole dependences of the thresholds for both optics are explained by (1) the betatron functions at the cavity, (2) the beam emittances and (3) the betatron functions at the octupole magnets.

REFERENCES

1. PHOTON FACTORY ACTIVITY REPORT, #6 (1988).
2. H. Kobayakawa, Y. Yamazaki, Y. Kamiya and M. Kihara, Jpn. J. Appl. Phys., 25, 864 (1986).
3. M. Izawa, H. Kobayakawa, S. Sakanaka and S. Tokumoto, Jpn. J. Appl. Phys., 26, 1733 (1987).
4. H. Kobayakawa, M. Izawa, S. Sakanaka and S. Tokumoto, Rev. Sci. Instrum., 60, 1732 (1989).
5. Y. Kamiya, M. Katoh, I. Honjo, A. Araki and M. Kihara, Proc. of the 1987 IEEE Particle Accelerator Conference (Washington, D.C., 1987), p. 455.
6. R. D. Kohaupt, IEEE Trans. Nucl. Sci., NS-22, 1456 (1975).
7. F. J. Sacherer, Proc. 9th Int. Conf. on High Energy Accelerators (Stanford, 1974), p. 347.
8. E. J. N. Wilson, CERN 77-13 (1977), p.121.
9. A. Hofmann and G. Muelhaupt, Proc. 8th Int. Conf. on High Energy Accelerators (Geneva, 1971), p.306.
10. T. Suzuki, KEK-74-6 (1974).