LOW EMITTANCE OPTICS OF PHOTON FACTORY STORAGE RING AT KEK

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Abstract

A new optics is being successfully tested at the Photon Factory Storage Ring (PF-RING) in order to reduce the emittance to 0.13 mm mrad, about one third of the present value. This optics with four additional quadrupole magnets is a modified version of one of the optics designed as an option at the early period of PF construction. One advantage of this new optics is that the beta-function at RF-sections is smaller than that of the old option. The other advantage is that the dispersion function is zero at the long straight sections for insertion devices and RF cavities. The aim of this paper is to describe the new low-emittance optics as well as the parameters of the new quadrupole magnets and power supplies. Some preliminary results of machine study will be also presented.

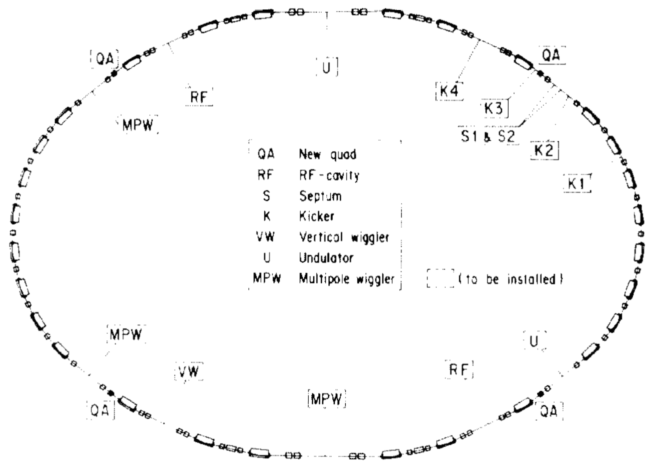

Fig. 1 Outline of PF-RING.

I. Introduction

The PF-RING is now being operated very stably and has been progressively improved since its completion of construction in February 1982. The status and progress of the PF-RING are summarized in PHOTON FACTORY Activity Reports[1]. The principal parameters of the present operation called the normal-emittance mode are listed in Table I. At the early stage of the construction of the PF-RING, four alternatives of optics including a low-emittance configuration had been designed[2]. However the optics that had been used in operation until recently was the same as the one used in the commissioning of the ring because of the financial defect to reinforce the power supplies of the ring quads, except the small changes of tunes mainly in order to avoid a transverse instability.

After enjoying the comfortable configuration with a rather high emittance for several years, the ring has been prepared to test a new low-emittance mode[3] through the fiscal year 1986 without cutting down the user times, in order to respond to the increasing demand for higher brilliance from the synchrotron light users. Up to now this new optics has been successfully tested, and is ready to go into operation in the user times.

In this paper, described are only the new optics, and the new quadrupole magnets and power supplies along with some of the preliminary machine studies, while many other improvements were indispensable for commissioning the new optics; the installation of RF damping antennas[4], the replacement of an air-core kicker with a new ferrite-core kicker[5] and the installation of a ceramic chamber at the kicker, the other replacements of vacuum chambers for the new quads[6]. Further the undulator with a narrow gap was removed for about one month to make the commissioning easy[7]. These will be reported elsewhere.

II. New Optics Configuration

The outline of the PF-RING is shown in Fig. 1 with four additional quads named "QA" that are needed for the new optics with a low emittance of about one third of the normal-emittance mode. The low emittance is attained by increasing the horizontal phase-advance in a normal cell from $\pi/2$ to $4\pi/5$, and by making up the triplet sections together with two bends near the centers of insertion sections into achromatic ones. In order to get a good matching of the optics between the end of normal-cell section and the insertion section, adding a new quad in-between was found to be necessary. By doing this, we can on one hand decrease the β-functions at RF- and VW-sections less than in the old option of low-emittance configuration and also make these sections dispersionless. On the other hand the space available to a kicker called K3 was found to be insufficient for the existing air-core kicker, so that the kicker has been replaced with the smaller one with a ferrite-core.

Table I. Principal parameters of the ring and the normal-emittance mode.

Energy	2.5 GeV	
Circumference	187.074 m	
RF frequency	500 MHz	
Harmonic number	312	
Stored current	nominal	300 mA without VW
		250 mA with VW
	max.	360 mA at 2.5 GeV
		520 mA at 2.05 GeV
Beam lifetime		20 hrs at 200mA

		(design)	/	(operation)	
ν_x		5.25	/	5.40	
ν_y		4.25	/	4.16	
α		0.040	/	0.037	
ξ_x		-6.6	/	-6.8	
ξ_y		-4.7	/	-4.7	
Emittance	(hori.)	463	/	404	(nm rad)
	(verti.)	----	/	~8	
σ_z		2.14	/	2.05	(cm)

The principal parameters of the new low-emittance optics are listed in Table II and compared with the parameters of the old one. Fig. 2 shows the β- and η-functions in a quadrant as well as the beam sizes for the new optics. The brilliances are expected to be improved about twenty times at two beam lines, about ten to five times at several ones, and about doubly at the others. Smaller β-functions are generally desirable at RF-sections to avoid transverse instabilities due to the higher modes of cavities, and also at the sections of the insertions with high fields to reduce their influence on the orbit parameters. In the case of PF-RING, the smaller horizontal β-functions at these sections are expected to make the

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Table II. Parameters of the new low-emittance optics and its comparison with the old option.

		(design)/(operation)	the old option
ν_x		8.25 / 8.40	7.25
ν_y		3.25 / 3.16	3.25
α		0.016 / 0.015	0.017
ξ_x		-13.2 / -15.8	-15.0
ξ_y		-7.6 / -8.6	-7.0
Emittance	(hori.)	128 / 127	166 (nm rad)
	(verti.)	--- / ~2.5	---
σ_z		1.4 / 1.3	1.4 (cm)
Stored current	nominal	300 mA without VW 250 mA with VW	
Beam lifetime		20 hrs at 200mA	

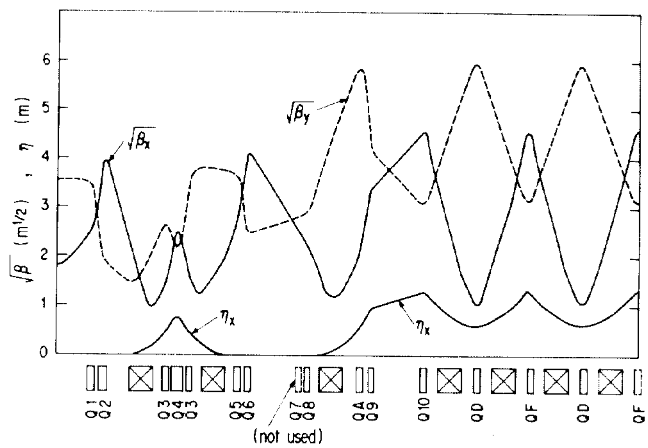

Fig. 2(a) β- and η-functions in a quadrant.

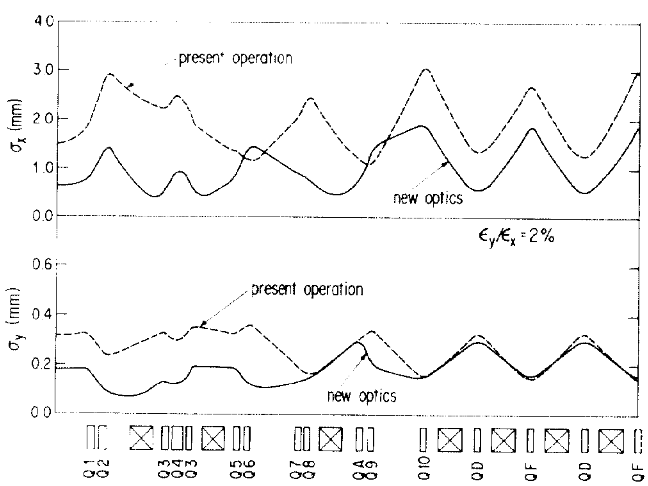

Fig. 2(b) the beam sizes in a quadrant.

operation of the ring much easier. Because two horizontal transverse instabilities were found to be dangerous in PF-RING, and the insertion device with a high field is the VW, the vertical superconducting wiggler with 5 T and with a narrow horizontal gap, which affects the horizontal orbit parameters more seriously. The horizontal β-function at the RF- and VW-section is shown in Fig. 3 together with those for the other optics. As seen in the figure, the β-function is smaller than that of the old option, but still larger than that of the normal-emittance mode, so that the transverse instabilities were anticipated to become more troublesome problems. Thanks to the hard work of RF group, however, the problems have been resolved by installing the damping antennas in RF-cavities.

Meanwhile, the new optics needs four quads in the straight sections as described above, but alternatively it does not use four existing Q7 quads in the long straight sections as seen in Fig. 3. Allowing to use the Q7 quads, however, we can obtain some other modified versions that would be more stable, though they have not been actually tried yet, one of which has about one half of the value of the β-function at RF- and VW-sections compared with the optics presented here.

Anyway, in future, if we decide to use the successfully tested optics alone in operation and to get rid of Q7 quads, the empty space in the long straight sections will be available, for example, to longer insertion devices.

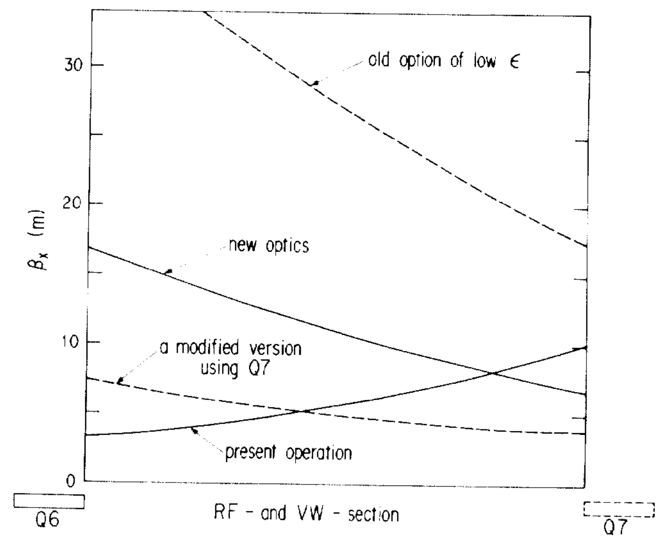

Fig. 3 Horizontal β-function at RF- and VW-section.

III. Magnets and Power Supplies

The design of the additional quads had to be chosen so as to accommodate the outside of a magnet yoke to one of the existing beam-lines at its place of installation. Then it turned out that the bore radius of the quads was to be shorter than that of the existing quads, and the outer shape of the magnet yoke to be in a polygonal form rather than a circular one of the existing quads. The parameters of the new quads are given in Table III and an octant of the magnet pole is shown in Fig.4. The end core shimming to get a good integral gradient was empirically determined in much the same way as in the case of the existing ones by simply attaching rectangular iron blocks to the end core. A part of the results of the field measurement are shown in Fig. 5. The new quads were fabricated HITACHI, Ltd.

Four new power supplies to increase the currents of some of the existing quads were also made by HITACHI, while the new quads, QA, are excited by adjusting one of the existing transistor-type power supplies. In addition, the other three of the power supplies were reinforced and adjusted in order to drive the quad currents needed for the realization of the new optics. The rearrangement of the cablings between the power supplies and the quads families was also made, with the capability to quickly resume its original arrangement. All existing power supplies including the ring bend power supply have employed transistors into the power regulation circuits, but because of somewhat large powers and also from an economical consideration, four new power supplies were decided to be made up with thyristors and active filters, following the design of the power supplies in the TRISTAN Main Ring.

Table III. Parameters of the new quads.

Bore diameter	104 (mm)
Core length	0.5 (m)
Field gradient(B'ℓ)	41.6 (max. 88.0) (kG)
Current	300 (max. 800) (A)
Turn number per pole	26
Resistance	37 (mΩ)
Max. power dissipation	24 (kW)
Water flow rate	2.4 (ℓ/min)

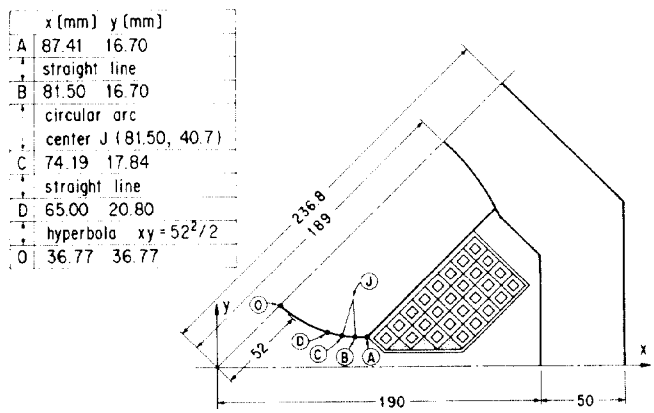

Fig. 4 An octant of the new quad.

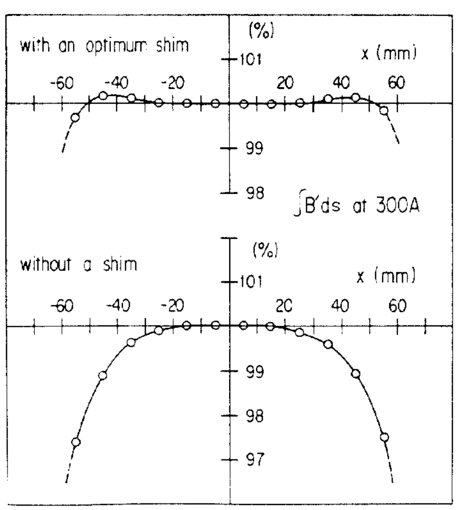

Fig. 5 Measurement of the magnetic field of the new quad.

IV. Preliminary Machine Studies

This section summarizes the preliminary machine studies of the new optics with putting emphasis on the orbit parameters. More details of the machine studies are reported in this conference or will appear in the papers presented by other groups of PF-RING.

Soon after setting up the new optics configuration and slightly adjusting the beam-transport line and the ring magnets, we succeeded in storing the beam into the ring without using any steering magnet. The injection rate attained so far is about 1 mA/sec with the repetition rate of 1 Hz. The maximum distortion of the horizontal and vertical closed orbits were corrected to less than about 1 mm. The fractional parts of the tunes were changed by adjusting only two quad families of QF and QD in the normal cells, so as to be almost equal to those of the normal-emittance mode. Then the distorted β-function were measured, and corrected by using the measured data[8]. Thanks to the accumulated experiences and careful studies on the VW together with a sophisticated method of the simultaneous correction of tunes and β-functions[9], we immediately succeeded in exciting the VW with a larger β-function at its location up to 5 T without any appreciable beam loss.

Through these machine studies, we have found two problems; (1) there are longitudinal instabilities as seen in the normal-emittance mode. However we can store the beam more than 300 mA, and may use this beam for the user times without any trouble, since the growth of the beam size due to the instabilities is still small. (2) The closed orbit was found to vary almost periodically from day to day with the maximum deviation of 0.6 mm, much larger than that of the normal-emittance mode, so that the users could not pursue the changes of the centers of light beams.

Then a quick decision has been made to try a global and digital correction method of the closed orbit[10]. Before applying the method, using the measured deviation of the closed orbit, a pattern of the currents to excite the vertical steerings has been calculated by one of the usual correction methods for the closed orbit. The global and digital method consists of two steps; (i) the position data of the light beam from a beam line that is dedicated for the machine studies is fed into a mini-computer, and then the mini-computer tells the magnet control computer that the position is now high (or low). (ii) The magnet computer then excites the vertical steerings and make up a global bump of the order of magnitude of 10 μm around the ring: so far only several steerings are found to be sufficient for this correction. From such a study for two days, it seems that this method does work well for a longer time.

In conclusion, the low-emittance optics has been successfully commissioned. And the user times with this optics are expected to start at the beginning of this March.

Acknowledgements

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