MEASUREMENT AND CONTROL OF LINEAR COUPLING IN THE PLS STORAGE RING*

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Abstract

Linear coupling constant is measured in the PLS (Pohang Light Source) storage ring by driving the operating tunes across the coupling resonance. The measured coupling constant is 0.8% without correction which is well below the design tolerance 10%. It is argued that the main source of linear coupling is the vertical closed orbit distortion at sextupoles, rather than quadrupole rotation errors. It is demonstrated that the linear coupling can be controlled by using four groups of skew quadrupole circuits wound on sextupoles.

1 INTRODUCTION

In a storage ring, there are sources of linear coupling between horizontal and vertical motions. They include quadrupole rotation error and vertical closed orbit distortion at sextupoles. Linear coupling is the main source of vertical beam emittance (and vertical beam size). As far as the quality of synchrotron radiation is concerned, it is desirable to reduce the coupling as small as possible. On the other hand, from the point of view of stable storing of high beam current, small coupling could lead to difficulties. First smaller vertical beam size means shorter beam lifetime due to Touschek effect. And it also means more sensitivity to ion effect, because the linear force between the electron bunch and the created ion bunch is proportional to $1/\sigma_y(\sigma_x + \sigma_y)$, where σ_x and σ_y are horizontal and vertical r.m.s. beam sizes respectively. Therefore in the PLS storage ring, extra skew quadrupole windings have been installed to have control over the magnitude of linear coupling according to necessity. In this paper, the present status of PLS linear coupling will be explained.

2 RESULTS AND DISCUSSION

Under the influence of linear coupling the ratio of maximum values for beam emittances in both planes is given by [1]

$$K = \frac{\epsilon_y}{\epsilon_x} = \frac{\kappa^2}{\Delta^2 + \kappa^2}, \tag{1}$$

where $\Delta = |\nu_{0x} - \nu_{0y} - N|$ with N being the biggest integer below $|\nu_{0x} - \nu_{0y}|$. Here ν_{0z} is the operating tune in $z = x, y$ plane and κ is called the coupling coefficient defined by [2]

$$\kappa = \frac{1}{2\pi}\int_0^L \sqrt{\beta_x\beta_y}\,p(s)e^{i[\mu_x - \mu_y - (\nu_{0x} - \nu_{0y} - N)2\pi s/L]}ds. \tag{2}$$

In this defining equation, $p(s)$ represents the sources for linear coupling. At quadrupoles,

$$p = k\theta, \quad k_q = \frac{B' L_q}{B\rho}, \quad \theta;\text{ quadrupole rotation error}, \tag{3}$$

and at sextupoles,

$$p = k_s\Delta y, \quad k_s = \frac{B'' L_s}{B\rho}, \quad \Delta y;\text{ closed orbit distortion}. \tag{4}$$

Also $p(s)$ includes additional skew quadrupoles which have been installed deliberately to cancel the above sources for linear coupling. In PLS, the skew quadrupole field is created by extra windings on the two poles of the sextupole magnets. Of 48 sextupoles, 16 magnets have this skew quadrupole windings. These 16 magnets are divided into 4 groups and each group consists of 4 windings connected in series. These 4 groups are located at symmetric positions of the ring. In PLS the tolerance of θ is 0.5 mrad, and the r.m.s value of Δy is around 0.5 mm. With these numbers, the quadrupole contribution to linear coupling is negligible compared with the sextupole contribution, because big values of sextupoles are necessary to correct the chromaticity, which is typical of third generation light sources. For the two families of sextupoles, $k_s = -6.5$, 4.5 m^{-2}, respectively, while for the strongest quadrupole, k_q is only 0.5 m^{-2}. Therefore the main source of linear coupling is the vertical closed orbit displacement at the sextupoles rather than the quadrupole alignment errors, and thus it is expected that the skew quadrupole windings of the sextupoles are effective for reducing the linear coupling. It is also clear from the above argument that the magnitude of linear coupling (and its correction) depends on the status of closed orbit correction, even though sextupoles keep the same strengths.

The linear coupling can be measured by driving the operating tunes across the coupling (difference) resonance. By changing one of the quadrupole power supplies appropriately, the tunes of horizontal and vertical motions are moved close to the coupling resonance, and finally the horizontal tune is transferred to the vertical tune and vice versa. The minimum separation is then identified as the coupling coefficient κ. The result for PLS is shown in

* Work supported by Korean Ministry of Science and Technology and Pohang Iron and Steel Compant

Fig. 1. Such a coupling can be mathematically decoupled using normal coordinates. Fig. 1 shows the decoupled tunes in normal modes. From this figure, we find that the minimum tune separation is 0.009. Thus substituting $\Delta = 0.28 - 0.18 = 0.1$ and $\kappa = 0.009$ we get $K = \epsilon_y/\epsilon_x$=0.008 where K is known as the coupling constant. Using K, both emittances are given by

$$\epsilon_x = \frac{\epsilon_n}{1+K} \quad (5)$$

$$\epsilon_y = \frac{K\epsilon_n}{1+K}, \quad (6)$$

where ϵ_n is the natural emittance which is 12.1 nm in PLS.

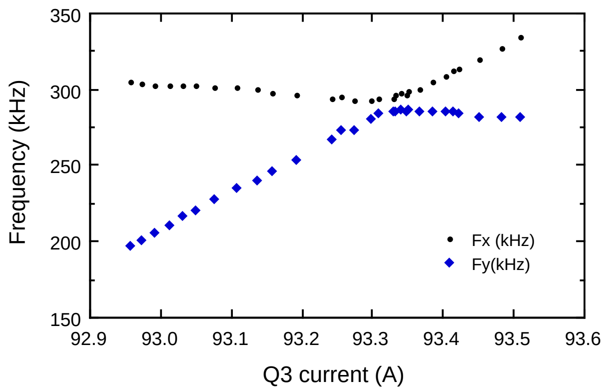

Figure 1: Variation of beam oscillation frequency as a function of a quadrupole magnet power supply current

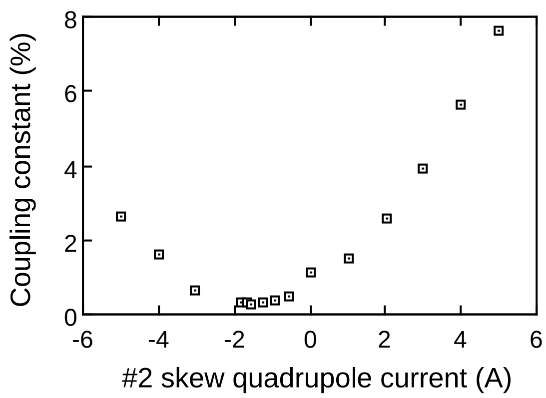

Figure 2: Variation of the coupling constant as a function of the current of skew quadrupole magnet power supply located at No. 2 sector of the ring

Even though the value of K=0.008 is already small enough, it can be further reduced by activating skew quadrupole windings. Activating just one group of skew quadrupole windings, K is reduced to the value of 0.004, which is demonstrated in Figs. 2,3,4,5. The value of K can be increased by controlling the skew windings as shown in these figures. Actually, the PLS linear coupling is varied from time to time according to our necessities.

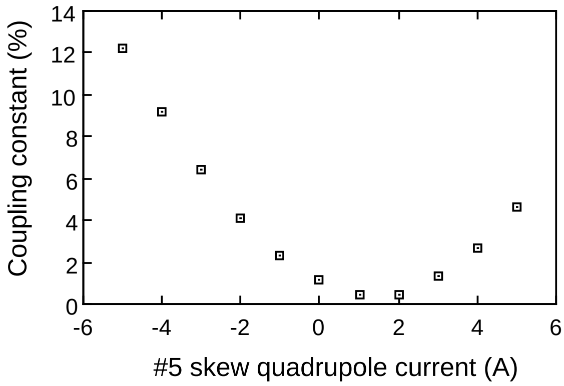

Figure 3: Variation of the coupling constant as a function of the current of skew quadrupole magnet power supply located at No. 5 sector of the ring

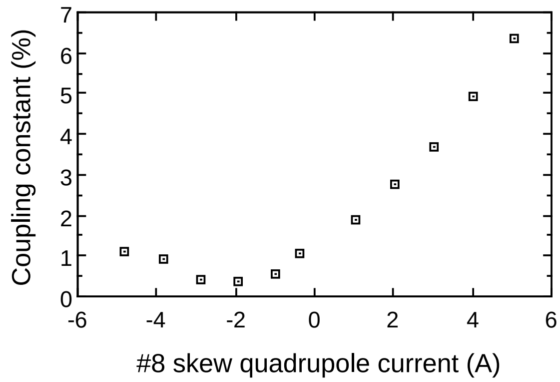

Figure 4: Variation of the coupling constant as a function of the current of skew quadrupole magnet power supply located at No. 8 sector of the ring

Beam lifetime is greatly dependent on the degree of coupling. At present, the beam lifetime in the PLS storage ring is mainly dominated by Touschek effect which is directly proportional to the inverse of the beam density. For the normal operation in the PLS storage ring, the coupling constant is kept to about 3% which gives about 15 hours of beam lifetime at 100 mA beam current. When the coupling constant is reduced to 0.8% which is the value in the absence of skew quadrupole circuits, the lifetime is reduced to about 10 hours at 100 mA.

3 SUMMARY

Linear coupling has been measured in the PLS storage ring. Without activating skew quadrupoles, the coupling constant was found to be 0.8% which is well below the design tolerance 10%. By exciting skew quadrupole current, the coupling constant could be reduced further down below 0.4%. Practically, the coupling constant can be controlled to any desired value by exciting one or more skew quadrupole circuits.

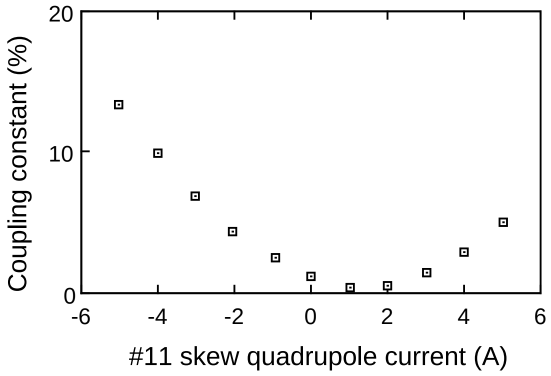

Figure 5: Variation of the coupling constant as a function of the current of skew quadrupole magnet power supply located at No. 11 sector of the ring

4 REFERENCES

[1] See e.g. H. Wiedemann, Particle Accelerator Physics II, (Springer-Verlag, Berlin, 1994)

[2] G. Guignard, CERN Rpt. 76-06 (1976)