A Machine Study on the Non-Interleaved Sextupole Scheme

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Abstract

The non-interleaved sextupole scheme is the most promising candidate for the chromaticity correction method of the KEK B Factory (KEKB) where we aim at an extremely low vertical beta value of 1 cm at the IP. An extensive machine study on this scheme was carried out using the present TRISTAN. In this paper we describe the results of the study focusing on a comparison between the dynamic aperture measured with calculated ones using the computer code "SAD"[4]. We also mention a new method to detect machine errors such as strength errors of quadrupole magnets or mis-alignments of sextupole magnets.

1 INTRODUCTION

In the design of the KEKB, the non-interleaved sextupole scheme (NISS) is seemed to be vital in order to keep sufficient dynamic aperture. The scheme was proposed in 1979 by K. Brown and R. V. Servranckx [1] for a chromaticity correction method of large rings. However, no machines so far have ever adopted this scheme. Then, we need very careful studies before deciding adoption of this scheme. Extensive computer simulations have been done on this scheme mainly for the design of the KEKB and have shown its superiority over the conventional interleaved sextupole scheme (ISS). The next step of the study is to see whether the excellent performance of NISS shown in the simulations is realized in an actual machine or not. For this purpose a machine study on NISS was carried out in autumn 1993 by using the present TRISTAN. Dedicated machine time of about a month was devoted to the study. Prior to the study, the cable connection scheme of sextupole magnets was changed to fit NISS.

We think that there are three points in this study. The first motivation of the study is to deny a possibility that this scheme does not work in principle or in actuality due to some unpredictable effect. The second point is to measure apertures with NISS and to compare them with the computer simulations. We think that this kind of comparison is very important, since our design of the KEKB so far has definitely relied on the computer simulations. The last point is detecting machine imperfections. This study is important in two senses. One is a sense that informations on the machine errors are necessary in comparing experimental results with the computer simulation. The other is that detection of machine imperfections (and their correction) itself is vital in our B factory to realize good machine performances.

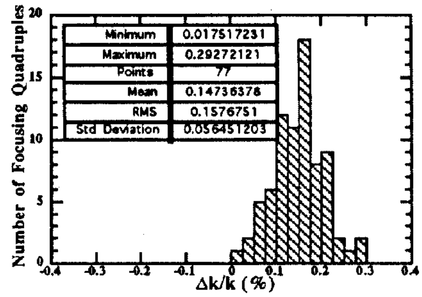

Figure 1: Strength Errors of QF magnets.

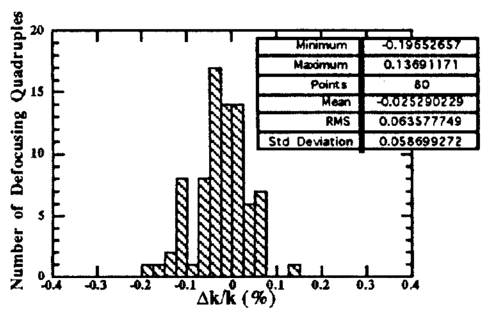

Figure 2: Strength Errors of QD magnets.

2 MACHINE ERROR DETECTION

We tried to measure two types of machine errors in this study; i.e. strength errors of quadrupoles and mis-alignments of sextupole magnets. A new method called "π-bump method" was introduced for the detection of these errors. A full detail of the method will be given in another paper[2]. In the following, we explain the method very briefly in the case of quadrupole strength errors. In the measurements local orbit bumps are intended to be made by two steering magnets. For this purpose the betatron phase advance between the two steering magnets in the horizontal or vertical direction is set to π. Since the normal cell and the RF cell have 90 degree phase advances, the π phase advance is naturally obtained with two cells. If there is no errors in strength in the quadrupoles between the paired steering magnets and if the two steering magnets are excited to the same strength, the bump is

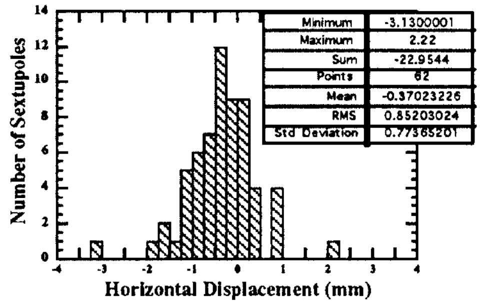

Figure 3: Horizontal Alignment Errors of Sextupoles.

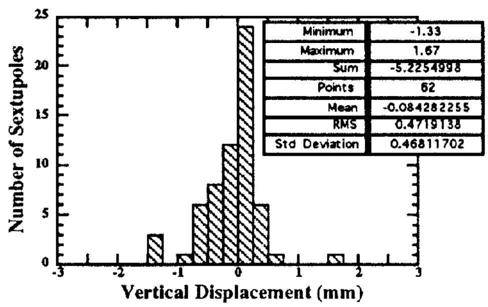

Figure 4: Vertical Alignment Errors of Sextupoles.

completely localized and there is no orbit leakage. If there are some strength error in the relevant quadrupoles, however, the bump does not close and some orbit leakage arises around the ring. A basic idea of this method is to detect the strength errors of quadrupoles by examining the leakage orbit. The orbit leakage from an imbalance between the two steering magnets can be distinguished from that arisen from the quadrupole strength errors by examining the phase of the leakage orbit. This is an important point of the method.

In this study, we inspected most of quadrupoles in TRISTAN. Fig. 1 and 2 show histograms of strength errors of quadrupole magnets located in the normal cells. The number of focusing quadrupoles (Fig. 1) or defocusing quadrupoles (Fig. 2) is plotted in vertical axis and the relative strength error in horizontal axis. In these measurements, the error of measurement is roughly estimated at 0.1%. This error comes from the resolution of the beam position monitors and drifts of COD during the measurements.

The alignment errors of sextupoles were also measured after the "π-bump method". The results are shown in Fig. 3 and 4. In these measurements, the error of measurement is roughly estimated at $100\mu m$. This error comes from the same origins as the quadrupole strength error measurement.

Accuracy of machine error measurements of the two types of errors mentioned above satisfies requirements in the KEKB[3].

3 APERTURE MEASUREMENT

3.1 Optics preparation

In the usual operation of the TRISTAN, the phase advances of normal cells are chosen as 60 degree. In this study we used 90 degree lattice for the normal cells to realize NISS. At the early stage of the study, we used a test lattice whose beta functions near IP are intended to change as smoothly as possible. With this test lattice we checked the measurement system. After this preparation, we squeezed the vertical beta function at one of the IPs to 3cm, which seems to be the minimum value with the configuration of the present TRISTAN. With this lattice we measured dynamic apertures.

3.2 Transverse Aperture Measurement

The measurements were done with a very small beam current, typically $1 \sim 10\mu A$ in order to avoid collective effects. We kicked the stored beam with kicker magnets, which are pulse magnets with pulse duration of 2 turns, in the horizontal direction or in the vertical direction and measured surviving currents as a function of kick angles. The calibration of the kick angle of the kicker magnets were done by using scrapers. We need to know the values of the beta functions at the scrapers in the calibration. Unfortunately we can not measure those values for the time being, since the quadrupole magnets beside the scrapers can not be excited independently. Then we could not help using the design values for the beta functions.

Table 1: Results of Aperture Measurement.

ν_x	ν_y	Horizontal ($10^{-5}m$)	Vertical ($10^{-6}m$)	E(%)
47.295	46.216	2.3	4.9	0.65
47.305	46.223	4.3	4.9	

Table 1 summarizes results of the aperture measurements.

In the study, we tried two different tune points. In the present study, the measurement errors are estimated roughly at 20%, which comes from the error in the value of the beta functions at the scrapers and so on.

Measured aperture are compared with the computer simulation. In the tracking, the measured values of the quadrupole strength errors and the sextupole alignment errors were used. In addition to these errors, we assumed the following (gaussian) random errors. The value of errors in the following correspond to 1 σ of the Gauss distribution. (1) Alignment errors of quadrupoles of $300\mu m$ in the horizontal and of $100\mu m$ in the vertical direction. (2) Rotation errors of bending, quadrupole and sextupole magnets of 0.2mrad . (3) Strength error of sextupoles of 0.2%. (4) Alignment errors of beam position monitors of $300\mu m$. Besides these errors, we counted the higher multiples of the final focus superconducting quadrupoles up to octapoles. With the errors mentioned above, the CODs (closed orbit distortions) were corrected in the computer. The typical residual value of COD was around 0.4mm.

Results of the trackings are shown in Fig. 5 and 6 together with the measured values. In the figures also the physical apertures are shown. One should note that the physical acceptance has also some error arising from the error of the beta functions. The measured value of the horizontal acceptance in Fig. 5 is well consistent with the tracking. On the other hand, the vertical acceptance of the ring is restricted by the physical acceptance. Due to a narrow physical aperture, we could not do crucial comparison between the measurements and the trackings in the vertical direction.

3.3 Longitudinal Aperture Measurement

First of all, we looked for a single turn injection condition, in which a particle at the center of a bunch is injected without any injection error, with scanning injection parameters. After this preparation, we transferred a beam in a very low intensity with changing RF phase and measured injection efficiency. In this way, we got a plot of injection efficiency as a function of RF phase. From this plot we can calculate the energy aperture. In this calculation we need the values of synchrotron tunes and momentum compaction factors of both the TRISTAN and its injector. In addition, we need the value of energy spread (or bunch length) of the injector. For the synchrotron tunes, we used measured values. On the other hand, for the momentum compaction factors and energy spread, the design values were used.

The measured values are also given in Table. 1. Due to restriction of machine time, we made a measurement at one tune point. The measurement error is estimated very roughly at 10%, which comes mainly from the error of momentum compaction factors.

The measured values of the energy acceptances are also plotted in Fig. 5 or 6. As is seen in the figures, the agreement between the measured values and the simulated ones is excellent.

4 SUMMARY AND CONCLUSION

By using "π-bump method" we could detect the strength errors of the quadrupoles with the accuracy of 0.1% and the alignment errors of sextupoles with $100\mu m$. These detection accuracies satisfactory meet the requirements of the KEKB. In the aperture measurements with NISS, we got excellent agreements between the measurements and simulations for the horizontal and the energy aperture. As for the vertical aperture, however, a narrow physical aperture prevented us from making crucial comparisons. Through the present machine study, we have had a confidence that the non-interleaved sextupole scheme has no principal or actual problems and works well. Then, this scheme seems to be very promising in the KEKB facility.

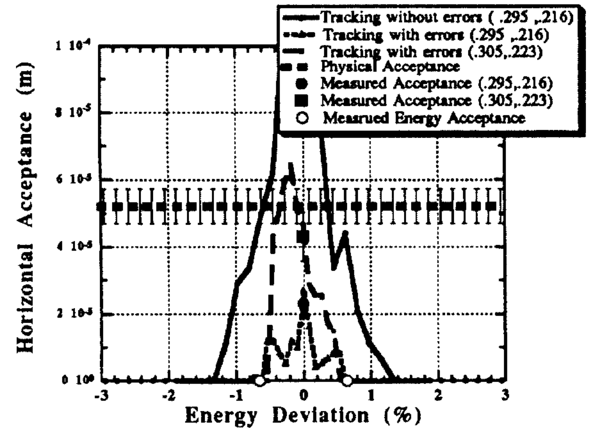

Figure 5: Horizontal Acceptance Measured.

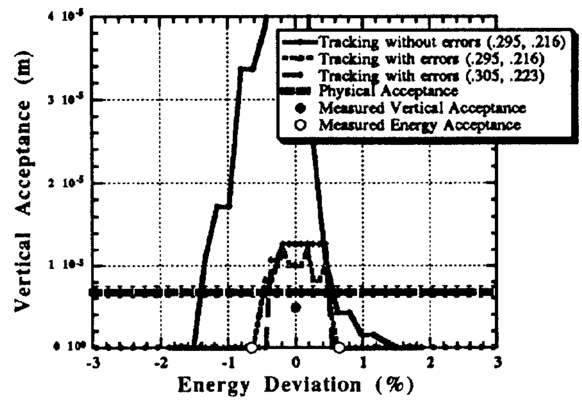

Figure 6: Vertical Acceptance Measured.

5 ACKNOWLEDGMENTS

The author wishes to thank Drs. H. Sugawara and Y. Kimura for their continuous encouragement to the study. He also acknowledges Dr. S. Kurokawa for arrangement efforts for the study and Dr. M. Yoshioka for negotiation with other experiment groups.

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