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D. Robin, G. Krebs, G. Portmann, A. Zholents, and W. Decking

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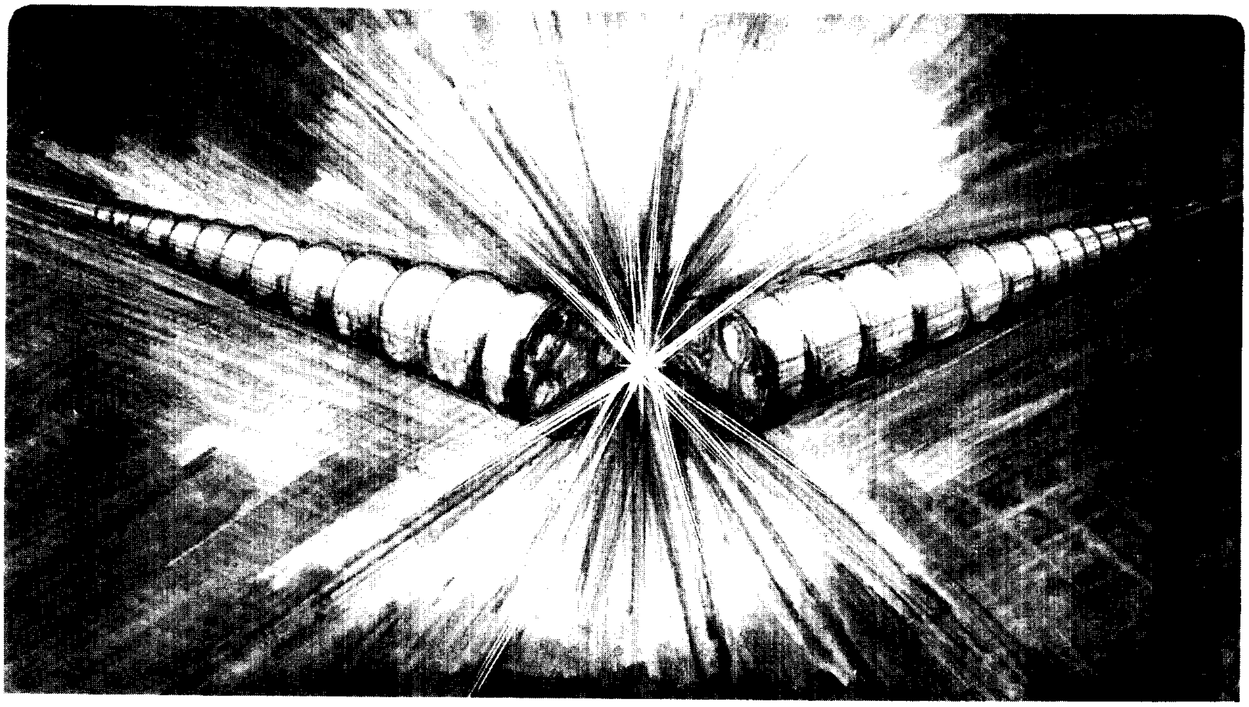

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REDUCTION OF NONLINEAR RESONANCE EXCITATION FROM INSERTION DEVICES IN THE ALS*

D. Robin, G. Krebs, G. Portmann, and A. Zholents

Advanced Light Source
Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

and

W. Decking

DESY, Hamburg, Germany

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REDUCTION OF NONLINEAR RESONANCE EXCITATION FROM INSERTION DEVICES IN THE ALS*

D. Robin, G. Krebs, G. Portmann, A. Zholents, Lawrence Berkeley Laboratory,
Berkeley CA 94720 USA, and W. Decking, DESY, Hamburg, Germany

Abstract

Theoretical studies of Lawrence Berkeley Laboratory's Advanced Light Source (ALS) storage ring predict strong field insertion devices will break the rings symmetry, increasing resonance excitation that may reduce the dynamic aperture and thus the beam lifetime. We have embarked on an experimental program to study the strength of nonlinear resonance excitation in the ALS when insertion devices are present. We observe an enhancement in the resonance excitation of a third-order resonance when the gap of the insertion device is narrowed. We also find that it is possible to suppress this resonance by detuning two quadrupoles on either side of the insertion device. The results of this study are presented in this paper.

I. INTRODUCTION

The ALS is one of the first members of a new family of synchrotron light sources called third-generation light sources. These new light sources are designed to generate a small beam emittance to enhance the brightness of the radiation emitted from insertion devices. In these rings the natural chromaticity is very large. This is due to the strong focussing quadrupole magnets that provide the small emittances. As a result strong sextupole magnets are necessary to correct the rings natural chromaticity.

The effects of alignment errors, magnetic field imperfections and insertion devices (undulators and wigglers) on the size of the dynamic aperture has been studied theoretically[1][2][3]. These studies have shown that the single most important parameter in causing the reduction in dynamic aperture is the distortion of the periodic betatron phase between the sextupole magnets. The linear focussing of an insertion device can distort the betatron phase to a such a degree that the resulting reduction in the dynamic aperture is greater than a lattice with random magnetic errors but no insertion device. Several linear compensation schemes were studied showing that the dynamic aperture can be restored to a large degree by using a global matching technique to minimize the distortion of the betatron phase[4]. In a earlier study [5] we observed the onset of resonances when the symmetry of the lattice was broken by deliberately detuning one quadrupole.

In this paper we report on the results of an experiment where we observe the onset of resonances when an insertion device is closed. By carefully adjusting a few select quadrupoles near the insertion device we were able to suppress a third order resonance to the same level when the undulator gap was fully open.

II. OBSERVING STRUCTURAL RESONANCES

When excited, structural resonances may alter the behavior of particles in the beams tail. Resonances may cause particles to increase and decrease their transverse amplitudes or to be trapped at large amplitudes. Therefore by monitoring changes in the beam tails as the betatron tunes are varied, it is possible to observe the onset of resonances.

The way in which we monitor the tails is by limiting the transverse physical aperture with a beam scraper and measuring the beam lifetime as a function of betatron tunes. If resonances are present in the vicinity of the tunes, more particles will hit the scraper when they make large amplitude excursions resulting in a shorter beam lifetime. If resonances are not present, fewer particles will hit the scraper resulting in a longer beam lifetime. Thus if we vary the betatron tunes while simultaneously observing the beam lifetime we will see the lifetime drop when we move onto excited resonances.

A. Experimental Method and Apparatus

The experimental technique was very similar to that used in VEPP-4 [6]—to measure the effect of the beam-beam force on the tails of the beam. A detector consisting of two plastic scintillators with photomultiplier tube outputs in coincidence (γ-telescope) was located just down-stream of a horizontal scraper. The γ-telescope detected gamma radiation emitted when electrons hit the scraper. The count rate detected is proportional to the rate at which particles hit the scaper and is related to the beam lifetime in the following way:

$$\text{Beam Lifetime} \;\alpha\; \frac{\text{Beam Current}}{\text{Detector Count Rate}} . \qquad (1)$$

We measure beam lifetime versus beam current and γ-telescope count rate and found that equation 1 was valid between beam lifetimes of 1 to 12 hours (see figure 1). Therefore by observing the change in the ratio of the beam current to the detector count rate as a function of betatron tune we were able to observe the onset of resonances. Because of the high counting rate of the detector (~1MHz), this technique is a faster and more accurate method of measuring changes in the beam lifetime than the more direct lifetime measurement of beam current verses time.

Our experimental procedure was the following. We would first change the tunes by changing two families of

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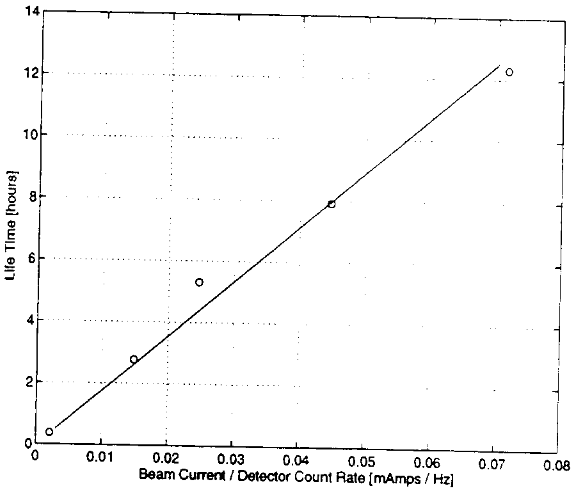

Figure. 1. Relationship between the beam lifetime and the detector count rate.

quadrupoles according to a previously measured transfer matrix. After the quadrupole fields settled we measured the beam current and the count rate in the detector for a 1 second interval. The whole process was automated and took about 2 seconds per tune point. In order to check how well our predicted tunes agreed with the measured tunes we periodically measured the tunes.

III. TUNE SCANS

We chose to scan in a region of tune space where two resonances are present: $5\nu_x = 72$ and $3\nu_x = 43$ (see figure 2). The resonance $5\nu_x = 72$ is allowed by the rings natural 12-fold symmetry . However the resonance $3\nu_x = 43$ is unallowed unless the 12-fold symmetry is broken. The $3\nu_x$ resonance is very sensitive to lattice errors because the strength of the resonance is linearly proportional to the strength of the sextupoles. Therefore even small lattice errors can cause an observable enhancement in that resonance.

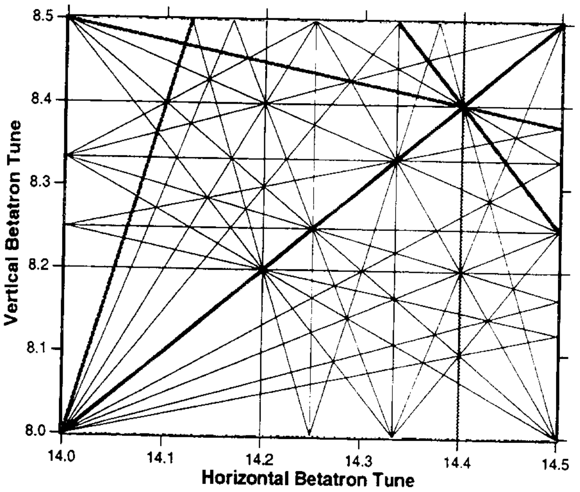

Figure. 2. Tune portait of all betatron resonances up to fifth order. The thicker lines are the allowed resonances.

A. *The "Unperturbed" Machine*

The first scan was made with the undulator gaps fully open. The scan covered a rectangular region in tune space ($14.3 < \nu_x < 14.45$ and $8.155 < \nu_y < 8.270$). Within this region we scanned 150 horizontal tune values by 10 vertical tune values ($\Delta\nu_x$ steps of 0.001 by $\Delta\nu_y$ steps of 0.012).

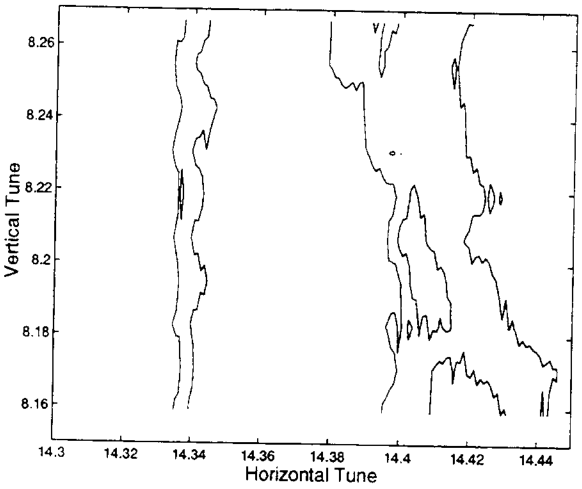

Figure. 3. Contour plot of the tune scan. Three resonances were clearly seen.

All the quadrupoles in each family were set to the same current value and all the insertion device gaps were open. Figure 3 shows the results of the scan. Three resonances can be seen in the scan:

$$5\nu_x = 72 \quad \text{(allowed)}$$
$$3\nu_x = 43 \quad \text{(unallowed)}$$
$$2\nu_x + \nu_y = 37 \quad \text{(unallowed)}$$

B. *Symmetry Breaking by Detuning 2 Quadrupoles*

Next we investigated the effect of detuning two quadrupoles symmetrically on either side of the sector 7 straight section. We scanned horizontally in tune ($\Delta\nu_x$ steps of 0.001) keeping the vertical tune constant ($\nu_y = 8.15$). We found that as the amount of quadrupole detuning increases there was an enhancement in the $3\nu_x$ resonance (see figure 4). In fact when the magnets were detuned by more than ± 2.5%, it was not possible to cross the $3\nu_x$ resonance without loosing a good fraction of the beam.

C. *Resonance Excitation from the Sector 7 Undulator*

We then investigated the effect of narrowing the gap of the U5 undulator in straight section 7. This undulator consists of 89 periods of 5 cm each. When the undulator is at its minimum gap (14 mm) there is a peak field on axis of ~1 T.

When the undulator gap was narrowed to 14mm we measured orbit, tunes, beta-functions, and resonance excitations and compared them with measuments taken when the gap was fully open. We found that the change in orbit was less than 100 μm in both planes. We measured a horizontal tune shift of $\Delta\nu_x = 0.003$ and a vertical tune shift

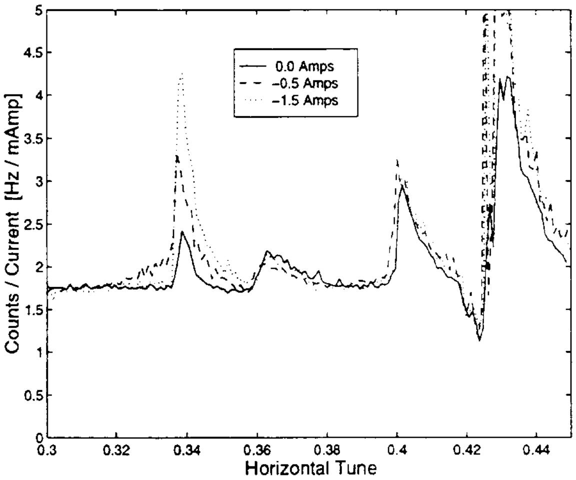

Figure. 4. Horizontal tune scans ($\nu_y = 8.15$) for undulator 7 gap open, closed and closed with QDs detuned.

of $\Delta\nu_y = 0.02$. By changing individual quadrupole fields and measuring tune changes we found a 10% change in the beating of the vertical beta function. (We were unable to measure the change in the horizontal beta function because the change was smaller than the resolution of our measurement.) At minimum gap there was an enhancement of the $3\nu_x$ resonance (see figure 5). However there is no enhancement of the $5\nu_x$ resonance.

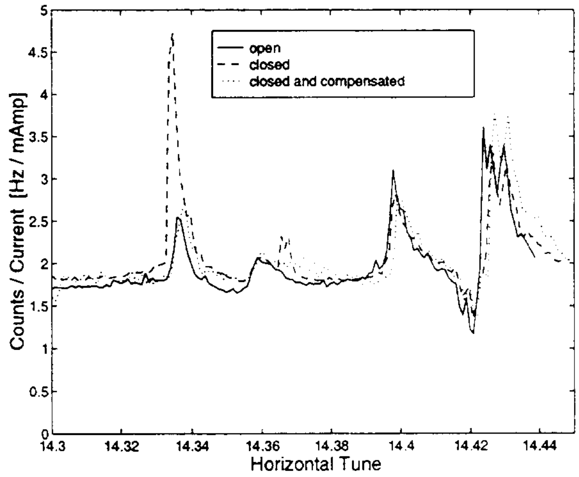

Figure. 5. Compensation of the $3\nu_x$ resonance ($\nu_x = 14.3333$).

In order to suppress the excited $3\nu_x$ resonance we detuned two quadrupoles on either side of the undulator. (These are the same quadrupoles which were discussed in the previous section.) These two quadrupoles were chosen because simulations predicted they would be very effective at suppressing the beta beat and phase distortion.

We found that by detuning the quadrupoles we are able to suppress the resonance (see figure 5). The optimal value of detuning the quadrupoles was found to be about -1%. The resonance was suppressed to the same level when the undulator gaps were fully open (see figure 5).

IV. INTERPRETATION OF THE RESULTS

The condition for minimum resonance excitation corresponded to a quadrupole detuning of -1%. Since we did not have a direct measurement of the distortion of the horizontal betatron function we tried to infer the distortion indirectly by introducing a quadrupole component in the model of our undulator which generated the measured horizontal tune shift. From the model we then extracted the distortion of the betatron function, about +2%. Furthermore from the model we predict the settings for the quadrupoles which minimized this distortion. To minimize the distortion the model predicted that the quadrupoles should be detuned by +2%. This optimal detuning is opposite in sign from what was found experimentally (-1%).

We repeated these measurements on several occasions with similar results. Moreover we found a similar result on another undulator in the ring (U8 in sector 9). In order to resolve this conflict we intend to look at the effects of vertical resonances because the distortion of the betatron amplitude and phase is larger in the vertical plane and are directly measurable.

Acknowledgments

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