Measurement of Chromaticity-Energy Spread Product by Transversely Kicking the Beam

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Abstract

A method for measuring the product of the chromaticity and the energy spread of a stored electron beam is presented. The technique involves observing the free betatron oscillations resulting from a short kick to the stored beam. Because of the positive chromaticity, the betatron oscillation amplitude is modulated. The ratio of maximum to minimum modulation amplitude is proportional to the product of the chromaticity and the energy spread. If the chromaticity is known, this method provides a useful tool for calculating the energy spread. The advantages and the disadvantages of the method are also discussed.

Introduction

Aladdin is a 1 GeV electron storage ring located at the Synchrotron Radiation Center of the University of Wisconsin, Madison. It has been in operation as a synchrotron radiation source since 1985 with average accelerated currents of about 200 mA. It has been observed that after an injection kicker magnet is pulsed in the presence of a single bunch stored beam, the envelope of the betatron oscillation from a horizontal pickup is amplitude modulated at the synchrotron oscillation frequency (Fig. 1). This phenomena is explained as the "beating" of the collective betatron oscillation for electrons of differing energies. After a detailed study of this phenomenon[1], it was found that the value of the product of the chromaticity and the energy spread can be measured from these signals. In the next section the theory is developed. That is followed by experimental results, including comparison with energy spread values obtained from direct measurement of the bunch length.

Theory

After the stored beam is given a short angular impulse, each electron inside the bunch will execute a free betatron oscillation with respect to the original orbit. The signal received from a beam position pickup is proportional to the displacement of the center of change (or mass) of the whole bunch of electrons. Each electron has an energy difference, ΔE_i, with respect to the synchronous electron. If the horizontal chromaticity is not equal to zero, then electrons with different energy will execute free betatron oscillations with different ν_i,

$$\nu_i = \nu_0 + \xi \frac{(\Delta P)_i}{P} = \nu_0 + \xi \frac{(\Delta \hat{P})_i}{P} \cos(\nu_s \omega t + \psi_i). \quad (1)$$

After some betatron oscillation periods, the signal from the pickup becomes smaller because electrons are no longer in phase, i.e. the displacement of the center of charge is smaller. The center of charge displacement as a function of time is given by

$$\bar{D}(t) = \frac{1}{N} \sum_{i=1}^{N} A \cos\left(\int_0^t \nu_i(t')\omega dt' + \phi\right), \quad (2)$$

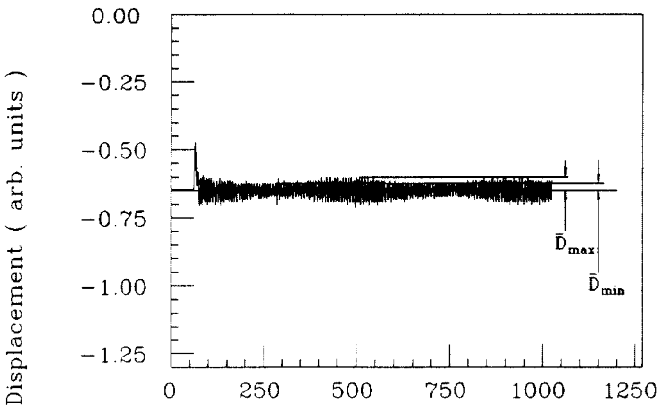

Fig. 1 The beam signal from the pickup

where N is the total number of electrons and ω is the angular revolution frequency. Notice here that the initial phase ϕ is the same for all electrons since they are assumed to be given the same transverse impulse.

After one half of a synchrotron oscillation period, the betatron oscillations appear very incoherent. But, if nonlinear effects are negligible, after one synchrotron period all the electrons will be in phase again and the displacement of the center of charge will be almost the same as just after the kicker was fired (except for a very small damping effect). The ratio of the maximum oscillation amplitude to the minimum oscillation amplitude depends only on the value of $\frac{\xi}{\nu_s}\frac{\sigma_\epsilon}{E}$, with

$$\frac{\bar{D}_{min}}{\bar{D}_{max}} = F\left(\frac{\xi}{\nu_s}\frac{\sigma_\epsilon}{E}\right). \quad (3)$$

The universal function F[1] is plotted in Fig. 2.

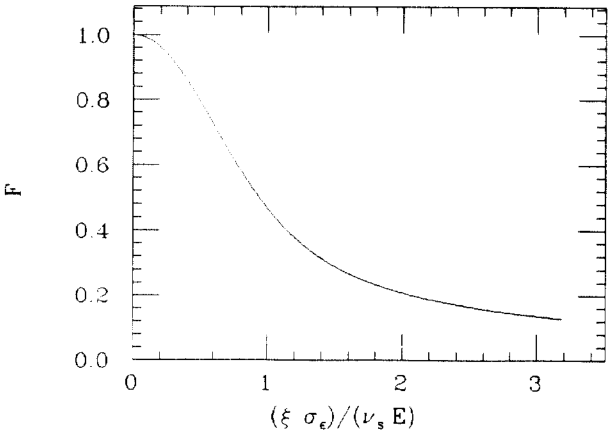

Fig. 2 Universal function F

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*Work supported by the NSF under contract DMR-8601349

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Experiments

The measurements were made on the Aladdin storage ring running at 400 MeV and in a single bunch mode. A single beam position monitor electrode is connected to a pulse stretcher. It is necessary to lengthen the 1 ns bunch length to about 100 ns for the purpose of digitizing the signal. A Data Precision 6000, which can digitize a signal in 10 ns, is used to digitize and store the beam position on every revolution for 4096 turns. The instrument is clocked by the ring master oscillator. The data is then transfered to a VAX 750 for analysis. The chromaticity measurements were made by varying the ring rf frequency and measuring the betatron tune with a Tecktronix 492P spectrum analyzer. The energy spread data in Table I is obtained by using the above technique.

Results

Table I. Data taken by new proposed method.

ξ	$I(mA)$	$rf(kV)$	$\frac{\sigma_\epsilon}{E} \times 10^{-4}$	$SD(\times 10^{-4})$
3.26	0.35	9.5	4.00	0.105
	0.27	19.4	4.18	
	0.24	29.5	4.25	
5.07	0.17	9.5	3.94	0.078
	0.15	19.4	3.77	
	0.15	29.5	3.78	

For comparison, the energy spread data in Table II is obtained by measuring the bunch length directly and converting it to energy spread. The bunch length in Table II is measured by connecting a fast (1 GHz) oscilloscope to a so called "Q" electrode in the ring. This electrode is a cylindrical sleeve about 10 cm long inside the vacuum chamber through which the stored beam passes. The beam is capacitatively coupled to the electrode and, for long bunches, accurately displays the longitudinal bunch distribution. For short bunches, however, the limited band pass leads to measurement errors. According to a ZAP[2] calculation for Aladdin conditions, all of the data are taken at currents below the threshold of the microwave instability. Therefore the energy spread should be a constant, and the standard diviation of the energy spread value is an indicator of how good the results are. The column labeled SD in the tables is the standard deviation.

Table II. Data taken using Q-electrode signal.

ξ	$I(mA)$	$rf(kV)$	$\frac{\sigma_\epsilon}{E} \times 10^{-4}$	$SD(\times 10^{-4})$
3.26	0.35	9.5	2.91	0.502
	0.27	19.4	3.33	
	0.24	29.5	4.12	
5.07	0.17	9.5	2.93	0.264
	0.15	19.4	3.33	
	0.15	29.5	3.57	

Looking at the Table I data, since the currents are low, the bunch length should be independent of the chromaticity. A 10% error in the chromaticity measurement can easily account for this difference. Using different kicking strengths has shown that there is no significient difference as soon as the amplitude of the oscillation is large enough to get good resolution.

Conclusions

The technique described above provides an easy method for the measurement of energy spread. This method is especially attractive in situations where other methods may be difficult to implement, e.g. trying to measure the energy spread by measuring the bunch length when the bunches are very short. The accuracy of the measurement does rely on known values of the chromaticity and synchrotron oscillation tune. These can be very accurately measured. Care must be taken not to kick the beam too hard, since the measurement relies on the individual betatron oscillations remaining coherent for several synchrotron oscillations. That can be easily checked by observing that the second maximum oscillation amplitude is as large as the first.

Ackonwledgment

The authors want to thank the accelerator development and operations groups for their help with the machine experiments and for numerous fruitful discussions.

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