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DIRECT MEASUREMENTS ON THE BEAM-BEAM INTERACTION AT SPEAR*

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Introduction

The electromagnetic field of one colliding beam on another acts as a strong nonlinear lens, causing a spread in wave number (ν). Both the ν spread and its upper limit, $\Delta\nu_0$, have been invoked as causes of the beam-beam current limit in storage rings.[1,2] The extent of the spread has been searched out at other rings by studying workable operating regions in ν_x, ν_y space.[3,4] We have studied small changes in the sizes of colliding beams caused by external transverse excitation of one beam over a range of betatron frequencies. The results of the measurements are interpreted as tune shifts and tune spreads.

Measurement Technique

A single stored beam at equilibrium can be excited into betatron oscillations by applying a transverse oscillating electric field at the betatron frequency f_β or at frequencies sufficiently nearby.

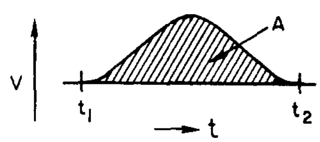
$$f_\beta = f_r |n-\nu| \quad ,$$

where f_r is the revolution frequency in the ring, ν is the betatron tune and n is any integer; in practice, the first integer above ν. Such a resonance has a finite width, often dominated by power-supply ripple, and includes damping phenomena and nonlinearities in the magnet lattice.

Usually it is the coherent resonance width which is measured, with antennas which detect the spatially average electromagnetic field of the particle beam. It is also possible to measure the response of the beam transverse size to transverse or longitudinal excitation.

An optical profile monitor using synchrotron radiation is a standard device in electron-positron machines.[5] In SPEAR,[6] we have an image-dissecting system which produces a train of profile scans for display on an oscilloscope. For a constant beam current, the area of each of the voltage pulses,

$$A = \int_{t_1}^{t_2} V(t)\,dt \quad ,$$



is constant, independent of changes in beam dimension. Thus the peak amplitude is inversely proportional to pulse width. With a peak-detecting circuit whose output feeds a recorder (Fig. 1h), one may plot the size response of the beam to excitation. This response is often quite different from the coherent response.**

The output of the optical monitors is often noisy, and the beam itself can be unstable, so one must use noise-suppression techniques in order to see small beam-size changes clearly. We use a lock-in technique (Fig. 2) in which the beam excitation is modulated with a square wave at approximately 1 Hz and the output of the peak detector circuit (Fig. 2e) is synchronously demodulated.

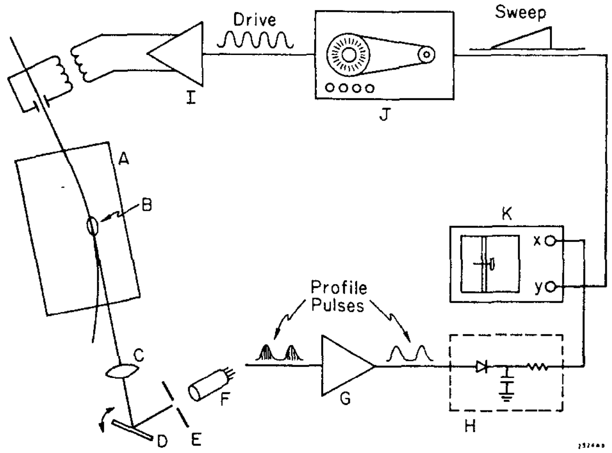


FIG. 1--Experimental equipment excluding lock-in

A. bend magnet	F. photomultiplier
B. beam	G. amplifier
C. lens	H. peak-detector circuit
D. oscillating mirror	I. excitation amplifier
E. slit	J. sweeping oscillator
	K. x-y recorder

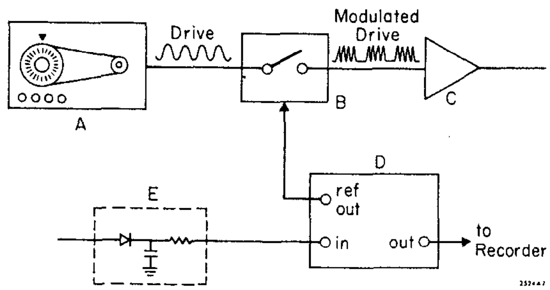


FIG. 2--Synchronous modulation of beam excitation and demodulation

A. sweeping oscillator	D. lock-in amplifier
B. electronic switch	E. peak detector
C. beam excitation system	

When this size response technique is applied to a beam in collision with another, we see a broad peak (Fig. 3) which we interpret as a tune-spread response. In general, there is no detectable broad coherent response when one stimulates colliding beams, only isolated resonant responses. The limiting sensitivity of our tuned receiver[7] is such that we can detect coherent signals which are 10^3 times smaller than the resonant response of the same beam not in collision.

The strong nonlinearities of the field of one beam on another cause a spread of wave numbers, the upper limit of which is the optical tune shift.[8] We observe that the exciting field couples to the beam, for the beam-size changes, but it does not couple in a coherent way. Rather, the particles whose f_β lie close to the exciting frequency gain

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**The germ of the ideas which led to this measurement technique originated in discussions with M. Matera of Frascati.

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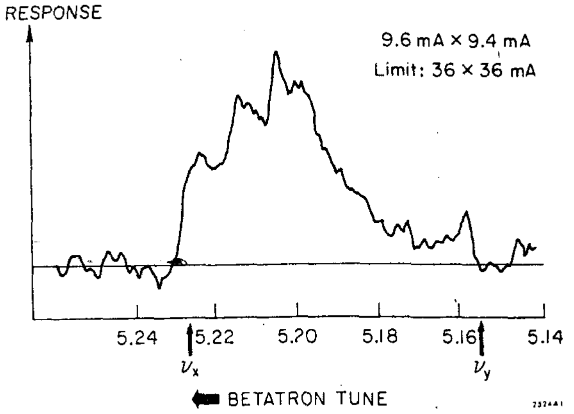

FIG. 3--Beam size response to excitation.

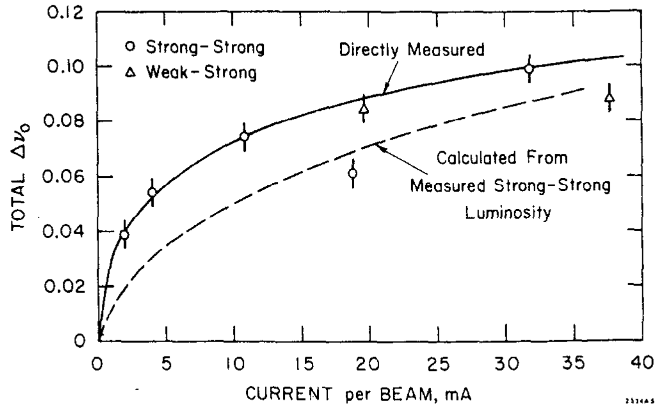

FIG. 4--Measured tune shifts.

transverse energy, change frequency and are replaced by other particles which move into the same region of f_β. Some time after the excitation is switched on, the colliding beams reach a new equilibrium, with the entire excited beam having more transverse energy and being wider.

Although we have no analytic treatment of this effect, it seems that the magnitude of the coupling of the exciting field to the beam is proportional to the local density of particles near that f_β or the coupling strength of the particles at that frequency, or both.

In all measurements, the excitation has been kept small enough so that the beam sizes change by less than 10%, and we have observed no changes in measured luminosity to within ±5%.

As one beam widens, the other shrinks. Under some conditions, energy couples to beam B when beam A is being excited, and beam A shrinks. This effect can be confusing and is usually eliminated by reducing the amplitude of the exciting field.

Another problem is the coupling of energy between horizontal and vertical motions in colliding beams. We have not yet measured the magnitude of this coupling, but it may lead to difficulty when ν_x and ν_y are close enough so that the tune spreads in the two planes overlap.

There can be no problem with "pulling" of particles with the excitation, since the frequency sweep is very slow, and the lock-in modulation period is long enough to allow the particles to attain complete equilibrium with excitation off. A typical sweep rate is $\Delta\nu/\Delta t = 2\times10^{-4}$/sec and a typical lock-in modulation rate is 1 Hz.

Experimental Results

There are still many difficulties with the measurement technique, and the results we present are preliminary. Figure 4 shows tune shifts per interaction region for 1) colliding beams with the same currents (strong-strong), 2) a large-current beam colliding with a weak beam. The tune shift of the weak beam is plotted versus current in the strong beam.

At all equal-current points, the tune shift of the more diffuse beam, as seen on the optical monitors, was measured. There is no measurable difference in the weak-strong and the strong-strong case. Tune shifts for the equal-beam case, computed[9] from lattice parameters, beam currents, and measured luminosities, are also plotted.

Several of the response peaks in Fig. 2 are not noise, but repeat over many measurements at the same operating point, with different colliding currents. Most data show pronounced, repeatable structure of this type, and while we have no certain explanation, we suspect they may be due to resonances.

In some of the weak-strong measurements, strong, isolated responses appear with tune shifts more than twice the calculated tune shift. The peaks of these mysterious resonances do not have any harmonic relationship with the lower-tune responses.

Acknowledgements

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