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SPEAR II PERFORMANCE*

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Summary

The single beam and colliding beam performance of the SLAC electron-positron storage ring SPEAR II is described. The sevenfold increase in harmonic number in SPEAR II in comparison to SPEAR I has made significant changes in single beam behavior. Strong synchrobetatron resonances and a new transverse instability are observed and our first studies of these phenomena are described. Measurements on current dependent bunch lengthening are presented.

Introduction

The design and operating characteristics of the SLAC storage ring SPEAR have been described in several publications.[1,2] The program to increase the maximum energy capability of the ring from 2.5 to 4.2 GeV[1] was implemented during the summer of 1974, and in October 1974 operational testing of SPEAR II was begun. The major differences between SPEAR I and II are given in Table I. Reports on the performance of many of the new components can be found elsewhere in the proceedings: RF system,[3] klystron development,[4] short bunch production in SLAC,[5] power supplies.[6]

TABLE I

	SPEAR I	SPEAR II
Maximum Energy	2.5 GeV	4.2 GeV
Loss/Turn	230 keV	2.8 MeV
Accelerator Voltage Required	500 kV	6.6 MV
RF Frequency	50 MHz	358 MHz
Accelerator Stations	2 × 80 kW (2 single cavities)	4 × 125 kW (4 × 5 cavities)
Maximum Synchrotron Radiation to Vacuum System	-	300 kW
Magnet Power	2.5 MW	7 MW
Injection Energy	1.5 GeV	1.5 GeV
Injection Acceptance	10 ns	1.4 ns

Operation of SPEAR II for high energy physics research began in early November 1974 and the subsequent discoveries of the new particles had considerable impact on the scheduled development of SPEAR II to higher energies. The emphasis turned to operating the ring and the SLAC-LBL magnetic detector as a scanning spectrometer with good energy resolution and precision. With some minor modifications to computer control hardware and software, the ring was made to slew the energy of the colliding beams in 1 MeV increments at speeds between 2 MeV per minute to 2 MeV per hour. This technique has been successfully employed in the search for further particle resonances between 1.5 GeV and 3.0 GeV beam energy. During the study of the detailed properties of the particle resonances, the precision and reproducibility of beam energy was 100 keV.

In January and February of this year we returned to an operating mode where the 25% of the operating time devoted to ring development studies again concentrated on high current and high energy problems. The peak energy is presently determined by magnet power supply and RF system limitations and is approximately 3.7 GeV per beam. By the end of March this will increase to close to our design limit of 4.2 GeV. The maximum currents achieved at the injection energy of 1.5 GeV have been limited by instabilities and resonances and are discussed later. The highest luminosity achieved to date was $1.1 \times 10^{31} cm^{-2} sec^{-1}$ with 30 mA in each beam at 3.4 GeV beam energy.

The power lost by the beam through the excitation of high order modes in the accelerating structures and the vacuum system has been extensively studied and the results are presented elsewhere in these proceedings.[7]

In parallel with the high energy physics program, the Stanford Synchrotron Radiation Project has a large continuing program of ultraviolet and x-ray research.[8]

Injection

The injection system for beam into SPEAR has been previously described[1] and is unchanged, but because of the increased harmonic number the requirements on the SLAC beam are considerably more stringent. The injection time acceptance of SPEAR II is only 1.4 nsec. To achieve the short pulse length and corresponding time stability, a system has been developed which consists of a 10-nsec gun pulse followed by a 40-MHz transverse beam chopper. The timing signals for the above are developed from the SPEAR master oscillator and controlled from SPEAR. The loss of charge per pulse, due to the sevenfold reduction in pulse length, has been almost balanced by the higher peak current from a new gun.[5] In addition, we have increased the injection repetition rate from 20 to 30 pps and have recently achieved injection rates comparable to SPEAR I, e.g., 15 mA/min for e^+ and 80 mA/min for e^-.

To further decrease the average filling time and to improve beam stability at high currents, we plan to increase the injection energy from 1.5 to 2.5 GeV during July and August of this year. This entails not only a modification of the injection components but of the transport system from the accelerator to SPEAR. The injection repetition rate will increase to 60 pps.

Resonances

The high peak currents associated with operation in single bunch mode at 358 MHz has led to both qualitative and quantitative changes in beam behavior. From the beginning we were confronted with a large number of betatron resonances which gave considerable transverse growth to the beam and could lead to beam loss. Resonance mapping measurements have shown that these new resonances (not observed in SPEAR I) are synchrobetatron sidebands of the fundamental lattice resonances. In SPEAR II, the value of ν_s (i.e., synchrotron oscillation frequency/orbital

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frequency) lies between 0.025 and 0.06 and the third to the tenth sidebands of the integer resonances (i.e., ν_x or $\nu_y - n\nu_s = 5$) lie in the normal tuning range of SPEAR. These resonances have been measured to have significant strength leading to a reduction of beam lifetime or in more severe cases to beam loss. It has been observed that the sidebands of $\nu_y = 5$ are stronger than $\nu_x = 5$ and also that the sidebands of other lattice resonances, for example $\nu_x - \nu_y = 0$ and $\nu_{x,y} = 5.5$, are very weak. Only the first sideband of these latter resonances has been observed.

To attempt to understand the mechanisms responsible for driving the resonances we have concentrated on the sidebands $\nu_y - n\nu_s = 5$. (For the purpose of this discussion the strength of a resonance is defined as the relative increase in beam size on resonance. The beam size is a balance between the driving force and radiation damping plus tune versus amplitude spread from any nonlinearity of the lattice.) We have found that the strength of these sidebands is independent of both chromaticity and the value of the momentum dispersion in the standard cells which incorporate the RF system. They are, however, very dependent on the value of the β-function in the low β insertions (see Fig. 1). The energy and

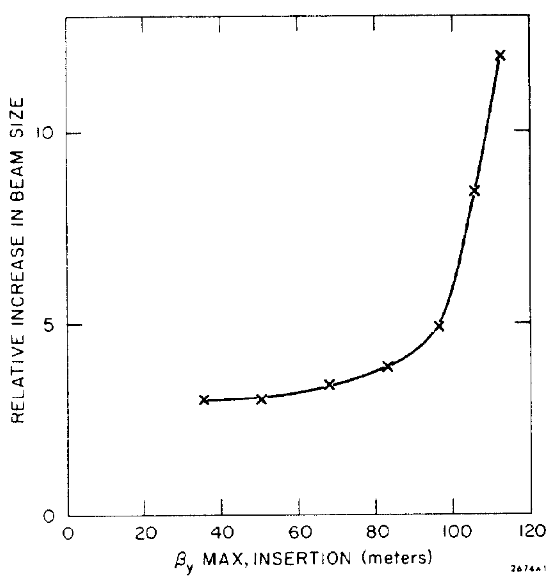

FIG. 1--The relative increase in beam size on the resonance $\nu_y - 5\nu_s = 5$.

beam current dependence of the strength of synchrobetatron resonances is intimately coupled to our understanding of bunch lengthening and any corresponding changes in momentum spread (see below); however, we see that the strength as defined above decreases with increasing energy.

To avoid the problems associated with these resonances, we have put the RF system under computer control so that we can control ν_s during energy changes from injection to the required operating energy.

Bunch Lengthening

As in SPEAR I, we have observed considerable current dependent bunch lengthening.[9] Figure 2 shows the bunch length, measured using a 100 psec photodiode, for several different RF voltages at 1.5 GeV. It can be seen that as the current increases the bunch length increases and tends toward a constant value. With the assumption that the betatron oscillation amplitudes are unaffected by bunch lengthening and are independent of current, we can derive the change in energy spread in the beam from measurements of

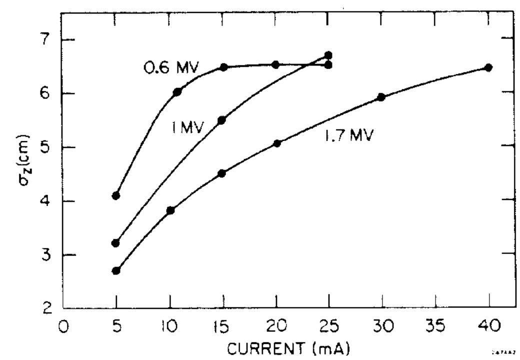

FIG. 2--Bunch length versus current for different RF voltages. E = 1.5 GeV.

the transverse beam size. Doing this, we see that the magnitude of the increase in energy spread is consistent with the bunch lengthening (see Fig. 3). The frequency spectrum

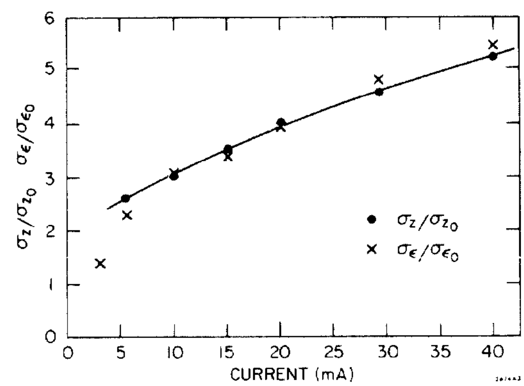

FIG. 3--Fractional increase in bunch length and energy spread versus current. E = 1.5 GeV.

obtained from a pickup electrode at high currents shows many lines at multiples of the synchrotron frequency and indicates at least qualitatively that there are many modes of phase oscillations within the bunch. It should be noted that the widths of the ψ particle resonances are small compared to the energy spread in the beams and this can be used to measure the current-dependent change in energy spread at these particular energies. The change in energy spread measured by this technique, over the limited current range allowed by the beam-beam limit, is in agreement with that derived from beam size measurements.

Figure 4 shows the bunch lengthening at different energies with the synchrotron oscillation frequency held constant as a function of energy. The measured energy spread increase is consistent with the bunch lengthening at all energies.

Instabilities

We turn now to transverse instabilities observed at SPEAR II. The head-tail instability is observed to have a similar threshold of a few milliamperes in both SPEAR I and II. Fast coherent damping with the lattice adjusted for positive chromaticity[10] is again observed. In horizontal betatron motion we have not observed any other current-dependent instability up to the highest single bunch currents achieved to date, i.e., 70 mA or 3.5 × 10'' particles in one bunch.

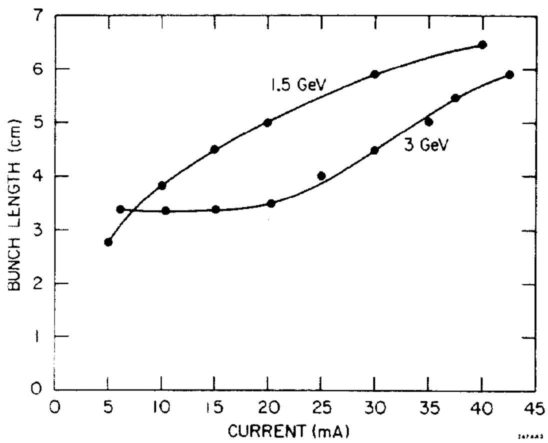

FIG. 4--Bunch length versus current for different energies.

We do observe a new vertical instability which has some unusual characteristics. At certain combinations of beam current and RF voltage, the beam bursts vertically to a large size but the coherent signal at the vertical betatron frequency, although detectable, is not large. If the vertical growth stays within the storage ring aperture, the growth limits. Then the beam damps back to a small size. This fluctuation in size can cease again at high beam currents, then return at still higher currents, where the growth on each burst exceeds the aperture and limits the current. In Fig. 5 we illustrate in a qualitative way the beam behavior at different RF voltages.

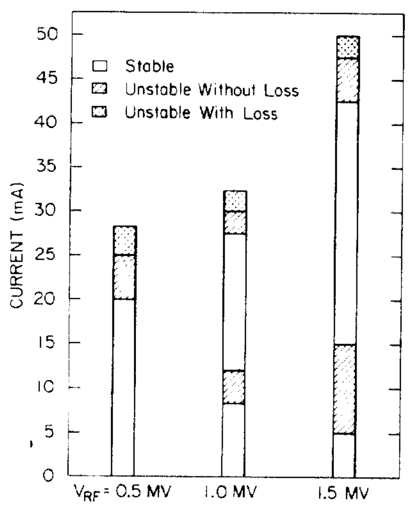

FIG. 5--Vertical stability versus current for different RF voltages. E = 1.5 GeV.

We have found that behavior of this instability is independent of betatron tune over a wide range, 5.15 to 5.55, and is independent of chromaticity ($\Delta\nu/\Delta p/p$) over the range 0 to 6. It has also been shown that closely spaced bunches are independent and, under a condition where a single bunch limited at between 25 and 30 mA, we have filled equally four neighboring bunches (2.8 nsec spacing) to a total current of 100 mA.

One may hypothesize that the rapid change in bunch length as a function of current and RF voltage may account for the complex "threshold" behavior of this instability. We have not yet been able to correlate these phenomena or identify any particular structure in the ring which may be responsible.

Two-Beam Performance

The performance of the colliding beams has been limited at the high energies by single-beam problems at 1.5 GeV during injection. Our rapidly improving understanding of the resonances and instabilities discussed above has allowed us recently to come close to SPEAR I's peak performance at 2.5 GeV and to exceed it at higher energies. Figure 6 shows the

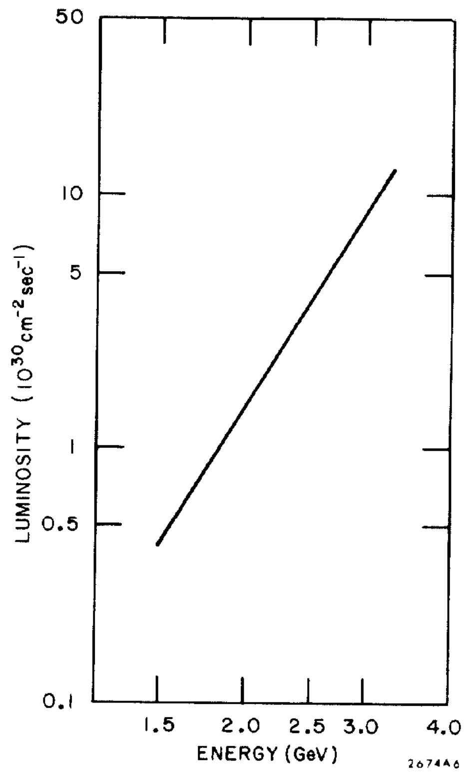

FIG. 6--Luminosity as a function of beam energy.

actual luminosity achieved to date as a function of energy and it shows the expected E^4 dependence. In the next few weeks we hope to extend this curve to 4.0 GeV. The values of beta functions at the interaction region used for colliding beam configurations are β_y = 7 cm, β_x = 1.2 m.

Acknowledgement

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