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A STUDY OF SPEAR AS A DEDICATED SOURCE OF SYNCHROTRON RADIATION

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Summary

We have studied the potential of SPEAR as a dedicated source of synchrotron radiation, based on the expectation that SPEAR will become increasingly available for this purpose as PEP, the 18-GeV colliding-beam storage ring now under construction by LBL and SLAC, becomes operational. A synchrotron radiation research program has been underway since May, 1974. Two beam ports capable of serving 9 simultaneous users are now operational. In single-beam multi-bunch operation high currents are possible (225 mA has been achieved and $\lesssim$ 300 mA is expected) and the electron beam emittance can be made smaller, resulting in higher source point brightness. Descriptions are given of SPEAR capabilities and of plans to expand the research capability by adding beam runs and by inserting wiggler magnets in SPEAR straight sections.

I. Introduction

The 4 GeV storage ring SPEAR at the Stanford Linear Accelerator Center has been used extensively for synchrotron radiation research during high-energy physics colliding-beam runs. A national facility, the Stanford Synchrotron Radiation Project (SSRP) began operation in May 1974[1] and now has the capability of conducting up to 9 experiments simultaneously on 2 tangential beam ports. The present facility[2-4] and its experimental program[4,5] have been described.

The extraordinary properties of the radiation from a multi-GeV storage ring (high and stable intensity over a broad spectral range extending from the visible through the ultraviolet and into the X-ray region, high polarization, extreme collimation, pulsed time structure, small and stable source size and position, and high vacuum environment) have made possible a large number of scientific and technological studies that would be extremely difficult or impossible with other sources. Coupled with similar experience on other storage rings (particularly the Tantalus I 240 MeV ring in Wisconsin, which has operated as a dedicated synchrotron radiation light source since 1968), synchrotron radiation has now become firmly established as a very powerful tool for research in physics, chemistry, biology and other disciplines over a wide spectral range.

There is now a clear national need[6] for increased and improved facilities for research with synchrotron radiation. In response to this need the Stanford Synchrotron Radiation Project has proposed a major expansion of its research facilities. Also, groups from the University of Wisconsin and the Brookhaven National Laboratory have proposed the construction of new storage rings to be dedicated only to research with synchrotron radiation.

The SSRP proposal calls for the construction of 7 new beam ports initially serving 14 experimental stations each equipped with a monochromator. Also proposed are 2 wiggler magnets to be inserted into SPEAR sections to provide enhanced synchrotron radiation.

To date, the SSRP program has utilized radiation produced during high-energy physics, colliding-beam runs of SPEAR. Under these conditions, currents are limited to 5-35 mA due to beam-beam interactions. Furthermore, the collision process results in an enlargement of the electron beam emittance by a factor of 2-10 and a corresponding reduction in source brightness. Brief experience with dedicated synchrotron radiation research operation of SPEAR has demonstrated that significantly increased flux can be obtained on high current, high energy, single beam runs. Studies have been made which indicate that, in this mode of operation, further increases can be made in the synchrotron radiation flux delivered to an experiment by operating at even higher currents and with magnet configurations that minimize the electron beam emittance and thus increase the source brightness. The synchrotron radiation can also be enhanced by inserting wiggler magnets into straight sections of the ring. These are periodic magnetic structures which may also have a high magnetic field, and which modify or enhance the synchrotron radiation spectrum but produce no net displacement or deflection of the orbit.

This report describes the proposed expansion of facilities, and the capabilities of SPEAR as a source of synchrotron radiation, including the improvements that are anticipated in single beam runs dedicated to synchrotron radiation research.

II. Proposed New Research Facilities

The proposed expansion program extends over 3 years and provides for 7 new beam ports (including 2 from wiggler magnet sources) initially equipped with 14 monochromator systems. These facilities would be accommodated in a new, 2-level experimental hall along the SPEAR south arc as shown in Figure 1 and are compatible with colliding beam operation of SPEAR.

As now conceived, the new beam ports will be of 3 general types utilizing radiation from 2 different source points in SPEAR bending magnets and also from wiggler magnets in SPEAR straight sections. Each beam port could serve several experimental stations and will be designed in the manner of the first 2 beam ports to permit independent access to each station. More information about the design of beam lines and the source properties of SPEAR are given in Reference 4.

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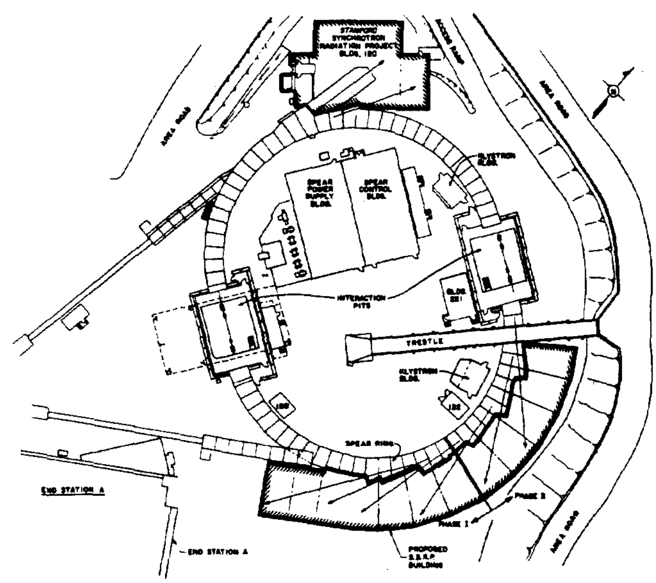

Proposed New Beam Lines and Experimental Hall on the SPEAR South Arc.

Figure 1

III. SPEAR as a Source of Synchrotron Radiation

SPEAR has operated almost exclusively as a colliding beam machine. There have been, however, about 8 hours of machine physics study of high-current, multibunch, single-beam operation and about 60 hours of research operation in this mode. We list here the performance levels that have been achieved to date; i.e., those achieved during colliding beam and brief single beam runs.

Stored Beam Energy: 1.3 to 4.0 GeV has been routinely achieved.

RF Power: Four klystrons with a combined capability of 500 kW are now installed. Operation at the 320 kW level has been routinely achieved.

Injection: SPEAR injects from SLAC at 1.5 - 2.25 GeV with a maximum repetition rate of 60 Hz. Typically only 10 to 30 Hz is used and fill rates of 50 mA/min of electrons in one-bunch mode are routinely achieved during colliding beam runs. During 8 shifts of dedicated operation for synchrotron radiation research, fill rates up to 400 mA/min were achieved in multibunch mode with a 20 Hz injection rate.

Stored Beam Current: One-bunch single-beam currents up to 80 mA have been achieved. A limit of 50 mA is now set on such operation due to high mode heating of vacuum chamber components. Studies and modification to SPEAR aimed at increasing this limit are now underway. In brief trials of multi-bunch operation, 225 mA was easily accumulated at injection energy (2.25 GeV). A limit on stored beam current is set by vacuum chamber cooling limits of 150 to 200 kW for a single beam. During brief dedicated runs, 60 mA was stored at 3.7 GeV producing 78 kW of synchrotron radiation power. At the time the current level was limited by a damaged beryllium window.

During colliding beam operation, the initial stored beam current (limited by beam-beam interactions) now varies from 5 mA per beam at 1.5 GeV to 35 mA per beam at 3.7 GeV. One bunch per beam is used.

Stored Beam Lifetime: The decay of stored current in SPEAR is determined by the average pressure. Hence, lower lifetimes accompany larger synchrotron radiation power dissipation because of the outgassing effects of the radiation. Typically it takes from 2 to 6 hours for the current to decay to one-half its initial value.

Single Bunch Mode: This mode of operation, already perfected and routinely used at SPEAR, provides a unique sharply pulsed synchrotron radiation beam. Exceedingly short pulses (0.13-0.4 nsec) are separated by the 780 nsec orbital period. SPEAR has also operated in a brief trial in two- and four-bunch mode, in which the time between pulses is 390 and 195 nsec, respectively. Any pattern of filling the 280 buckets is now possible, thus, any bunch spacing from 2.8 to 780 nsec is available.

SPEAR Capabilities as a Synchrotron Radiation Source. The potential of SPEAR as a dedicated source of synchrotron radiation go well beyond the performance levels already achieved as described above.

In multi-bunch mode of operation SPEAR should be capable of storing very large average currents by filling many or all of the 280 possible RF bunches. A report[7] on the stored current capability of SPEAR concludes that at least 300 mA should be possible in this mode after further study has taken place and various modifications have been implemented.

The RF requirements and stored beam current capability under different conditions have been evaluated and are summarized in Reference 4. One limitation on stored current in SPEAR is the vacuum chamber cooling which may be unable to handle more than 150-200 kW of total emitted synchrotron radiation power from a single beam. If this were the only limit then the maximum stored beam current varies with energy as given below:

Stored Beam Energy (GeV)	1.5	2.0	2.5	3.0	3.4	3.8	4.0
Stored Current for 150 kW Synch. Rad. Loss (A)	4.29	1.35	.55	.27	.16	.10	.08

As mentioned earlier, single bunch currents are now limited by higher mode heating effects to 50 mA (35 mA for each of 2 beams in colliding beam mode). The power dissipated in higher mode losses varies as $N_b I_b^2$ where N_b is the number of bunches and I_b is the current in each bunch. Thus a single bunch with 50 mA current produces the same higher mode losses as 25 bunches with 10 mA each (total current = 250 mA), 100 bunches with 5 mA each (total current = 500 mA) or 280 bunches (the maximum number) with 3mA each (total current = 840 mA).

Synchrotron Radiation Source Point Brightness and Electron Beam Emittance. In many synchrotron radiation experiments higher flux on an experimental sample is obtained if the electron beam emittance, particularly the vertical emittance, ϵ_y, is reduced. If we assume that the vertical emittance is largely determined by cross-coupling of horizontal and vertical betatron oscillations, a coupling constant K may be defined such that $\epsilon_y = K^2 \epsilon_x$. Since K cannot be reduced to zero (K = 0.1 is usually assumed to be an achievable value, although smaller values have been achieved on SPEAR with careful alignment of ring components) we have investigated the possibility of reducing ϵ_y through reduction of ϵ_x.

A study has been made[8] which shows that substantial reductions should be possible in ϵ_x by changing the currents of SPEAR quadrupole magnets. Results of this study are given in Table I taken from reference 8.

Table I

Case	ν_x	ν_y	$\hat{\beta}_x$ m	$\hat{\beta}_y$ m	$\hat{\eta}$ m	β_x^* m	β_y^* m	η^* m	η_w m	ϵ_x mm-mrad
1†	5.26	5.26	75	62	2.79	1.00	.12	.008	.005	.454
2	6.48	2.94	69	128	2.07	12.0	.06	.000	.000	.179
3	7.65	3.23	89	47	1.12	0.85	.25	.398	.15	.108
4	7.19	3.98	66	165	3.18	4.94	.73	1.08	.25	.103

† Case 1 is the standard configuration used for colliding beams

The horizontal emittance depends quadratically[8] on the horizontal dispersion function in the bending magnets. Since this dispersion decreases with increasing betatron tune, ν_x, smaller horizontal emittance results when ν_x increases. As shown in Table I some typical SPEAR lattice configurations have been found with higher values of ν_x which have approximately one fourth of the normal horizontal emittance. These new configurations do not require changes in location of SPEAR magnets.

These higher values of ν_x would result in increases in phase difference between present injection kicker magnets resulting in injection difficulties, unless the β_x and η_x functions are made non-periodic in the magnet cells. It is possible to devise an injection configuration[9] with high ν_x but with approximately correct phase difference between kicker magnets although such a configuration may not have the lowest horizontal emittance. However, after injection the configuration may be changed, without loss of stored beam current, to a configuration with the same high value of ν_x but with the desired low emittance.

Injection trials have been successful with the above described scheme with $\nu_x = 6.25$, compared to the standard 5.25. After injection the configuration was changed, with constant ν_x, to a lower emittance configuration and measurements confirmed that the expected factor of 2 reduction in horizontal emittance was achieved. The vertical emittance was reduced by only 10-20% indicating that factors other than cross-coupling are important.

Contributions to vertical emittance can arise from[10] horizontal magnetic fields due to rotated bending magnets and vertical orbit errors in quadrupole magnets, cross-coupling of η_x and η_y due to rotated quadrupole magnets and vertical orbit errors in sextupole magnets. These effects may be reduced by more careful alignment of ring magnets, resulting in smaller distortions of the equilibrium orbit. Further reduction of orbit distortions, such as may be obtained with the use of orbit correcting elements built into SPEAR, should also result in a lowered vertical emittance.

We also wish to point out that the inclusion of wiggler magnets in a storage ring can serve either to increase or decrease the horizontal emittance depending on the value of η_x at the wiggler location.[8]

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