IEEE Transactions on Nuclear Science, Vol.NS-22, No.3, June 1975

DESIGN AND PERFORMANCE OF THE STANFORD SYNCHROTRON RADIATION PROJECT (SSRP)†

A. D. Baer,‡ R. Gaxiola, A. Golde, F. Johnson, B. Salsburg, H. Winick,
W. W. Hansen Laboratories of Physics;
M. Baldwin,‡† N. Dean, J. Harris, E. Hoyt, B. Humphrey, J. Jurow,
R. Melen, J. Miljan,‡‡ and G. Warren, SLAC
Stanford University
Stanford, California 94305

Summary

The Stanford Synchrotron Radiation Project (SSRP) is now in full operation as a national facility utilizing the intense ultraviolet and x-radiation from the storage ring SPEAR at the Stanford Linear Accelerator Center (SLAC). The experimenter-operated facility is designed to maximize access to, and utilization of the radiation by 5 or more simultaneous users, within the limits of parasitic operation on a high energy colliding beam storage ring. A novel experimenter-controlled personnel protection system permits independent access to each of 5 experimental areas. A vacuum monitoring and control system protects the storage ring vacuum from contamination, rising pressure, or catastrophic failure. The design and operation characteristics of these control systems and of the beam position monitoring and control system, vacuum system and thin beryllium windows are presented.

Introduction

The SSRP has been in operation since May, 1974, as a national facility for UV and X-ray research using synchrotron radiation from the storage ring SPEAR at SLAC. SSRP has been funded since June, 1973, by the National Science Foundation and is administered by the W. W. Hansen Laboratories of Physics at Stanford University. Contributions to the facility have also beem made by the U. S. Navy Michelson Laboratory at China Lake, California, the Xerox Corporation and the Bell Telephone Laboratories. SLAC exercises control over radiation safety and sets vacuum standards for experiments which connect on-line to the SPEAR vacuum system.

The research program includes studies of UV and X-ray photo-emission, extended x-ray absorption edge fine structure, low angle x-ray diffraction, protein crystallography, UV reflectivity, and x-ray Raman scattering. Details are given in the 1974 SSRP Users Group Meeting, obtainable on request from R. Dannemiller at SSRP, and in the 1974 Hamburg Conference on VUV Radiation Physics. Professor S. Doniach of Stanford is the Project Director and Professor W. Spicer of Stanford is the Consulting Director.

The facility is built around a single beam port on the SPEAR vacuum system, accepting 11.5 mrad of synchrotron radiation which was initially split among 5 simultaneous users. As a secondary program on SPEAR, the facility was designed to permit operation of 5 or more simultaneous synchrotron radiation experiments during SPEAR colliding beam runs with maximum protection for the SPEAR vacuum system and minimum involvement of SPEAR and SLAC operations personnel. Particular attention to 3 elements proved vital in achieving this goal. These are:

1. Vacuum system and vacuum interlocks.
2. Radiation shielding and personnel protection system.
3. Orbit monitoring and control.

In this report we present a general description of the facility with particular emphasis on the above 3 areas.

Plan of the Synchrotron Radiation Facility

A prefabricated steel building 12 m wide, 24 m long and 7.3 m high has been constructed adjacent to SPEAR as shown in Fig. 1 and 2. The building is well insulated and temperature controlled and has a thick (30 cm) concrete floor for stability. Vibration sources (such as compressors) are located outside the building and decoupled from the building and floor. A 6 m extension of the building is planned to accommodate a second beam run.

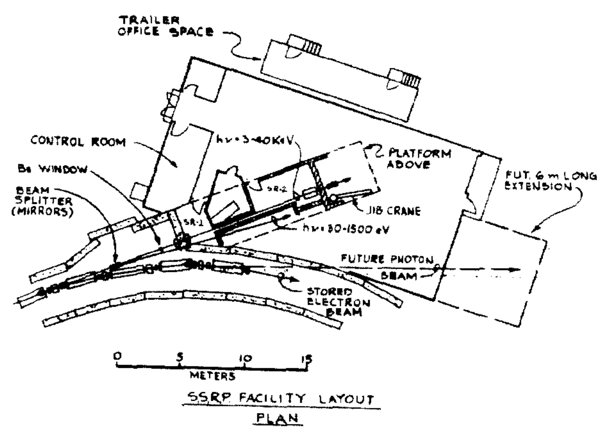


Fig. 1

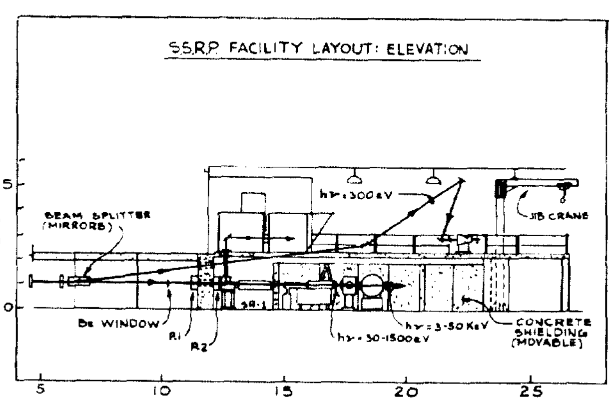


Fig. 2

†Supported by National Science Foundation Grant Number DMR73-07692 A02, in cooperation with the Stanford Linear Accelerator Center and the Energy Research Development Agency.

‡A. D. Baer is presently employed at Michelson Laboratory at China Lake, California.
‡†M. Baldwin is presently employed at the Dept. of Physics at Montana State University, Bozeman, Montana.
‡‡J. Miljan is presently attending Fresno State University, Fresno, California.

About 11.5 mrad of synchrotron radiation, corresponding to 15 cm of curved path in a SPEAR bending magnet, emerges tangentially into a high vacuum pipe. The spectrum of this radiation corresponding to SPEAR stored beam energies of 1.5 to 4.5 GeV is shown in Fig. 3. Single beam currents of 50 mA at 3 GeV and 100 mA at 3.8 GeV are anticipated during single bunch colliding beam operation. These currents are limited by beam-beam interactions. In single beam multi-bunch mode of operation larger currents (250 mA and 3 GeV and 500 mA at 2.5 GeV) should be possible. The SPEAR RF frequency is 358 MHz which is the 280th harmonic of the orbital frequency. In single beam runs ~ 200 bunches have been filled. The one bunch mode offers unique timing capabilities since the pulse duration is ≲ .3 nsec and repeats at 1.28 MHz. Other reports give more information about SPEAR[1] and the synchrotron radiation it produces.[2]

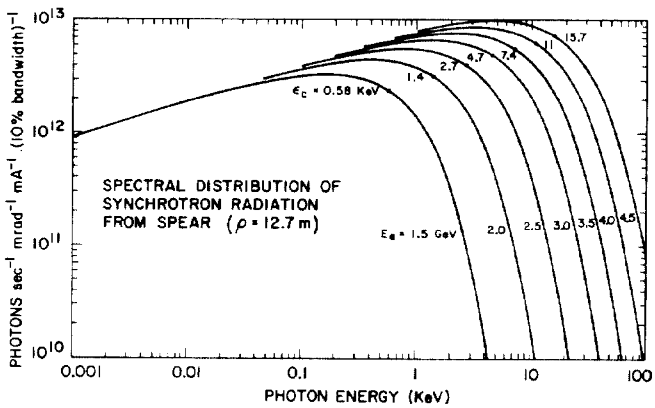


Fig. 3

The horizontal fan of radiation is split 3 ways by reflection at grazing incidence on 2 ultra smooth, platinum-plated copper blocks[3] placed 6.5 m from the source point. These mirrors may be remotely inserted and adjusted by experimenters during operation. Five or more simultaneous experiments share the radiation as shown in Fig. 4.

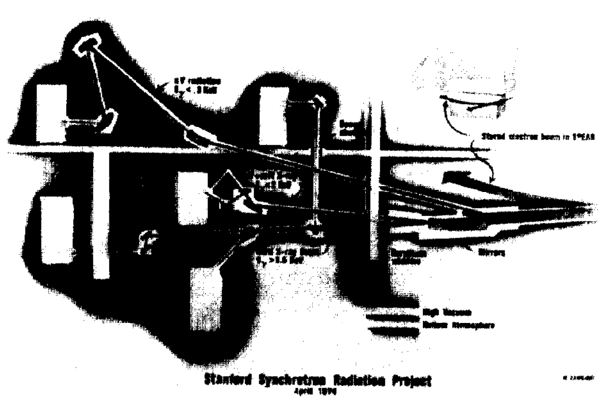


Fig. 4

One of the mirrors intercepts the outer 2 mrad of radiation at a horizontal grazing angle of incidence of 2° resulting in a horizontally focused 4° deflected beam. This mirror has an rms roughness of 65 Å and reflects photons up to about 600 eV. A smoother mirror is now in fabrication which should extend this energy to ≳ 1500 eV.

A plane mirror with an rms surface roughness of 30 Å intercepts the inner 3 to 6 mrad at a vertical grazing angle of incidence of 4°. The resulting beam rises at 8° and contains photons up to ~ 300 eV. Custom built high vacuum grating monochromators are connected to these lines. The mirrors are cooled thermo-electrically to enable operation with up to 25 W of synchrotron radiation per mrad.

The central part of the beam contains 4 to 10 mrad of radiation (depending on insertion of mirrors) which is not deflected by mirrors. This radiation proceeds down the high vacuum beam pipe and passes through a pair of 75 μm thick water-cooled carbon foils which absorb the UV and soft x-ray part of the spectrum. The radiation then leaves the vacuum system 10.5 m from the source point through a pair of 250 μm water-cooled beryllium windows.[4] This foil and window system begins to transmit at about 3.5 keV and reaches 50% transmission at ~ 4.5 keV. It is planned to improve this transmission by replacing the 75 μm foils with 5 μm pyrolitic graphite foils. A pair of such foils is now undergoing test in the beam run. In addition, a new beryllium window is planned with a total thickness of ≲ 100 μm. In combination with the pyrolitic graphite foils, this window should provide significant transmission down to 2 keV.

After emerging from the SPEAR vacuum system the x-rays travel in a helium atmosphere into a shielded area in which several crystal monochromators are installed. The helium system is carefully sealed and monitored to keep a high concentration of helium. For convenience the helium system is divided into several sections by 5 μ thick kapton windows. Each section has an independent helium input flow meter and output bubbler.

An elevated concrete slab 4.5 m wide, 12 m long and 2.4 m above the floor serves as a second level for installing experimental apparatus. Its thickness (20 cm) is adequate to provide shielding from the main beam line. Monochromatic x-ray beams and the rising 8° beam line vacuum system penetrate this slab as shown in Fig. 2 and 4. Electrical services, compressed air, and helium and water services are installed at several locations along the perimeter of the slab serving experimenters on both levels. A jib crane is used to bring heavy equipment to the upper level. Vacuum controls, radiation protection controls and signals to and from the SPEAR and SLAC control rooms are centralized in an adjacent control room.

Vacuum Systems and Vacuum Interlocks

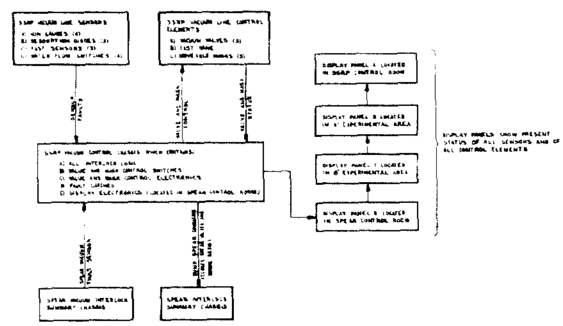
The vacuum system is built to SLAC specifications[5] and is all metal and bakeable. The central beam pipe extends to 10.5 m from the source, terminating at the beryllium window assembly within the SPEAR tunnel. The 4° and 8° beam runs continue in vacuum in the synchrotron radiation building and extend to 16 m and 25 m from the source point.

Four all metal, high vacuum gate valves isolate the beam runs from each other and from the SPEAR vacuum system. Water-cooled masks assure that synchrotron radiation strikes only water-cooled surfaces and 2 movable water-cooled absorbers may be remotely inserted to block the radiation. Four 110 l/sec triode ion pumps are used on the main beam line with additional pumps on the 4° and 8° beam lines.

All components of the vacuum system were chemically cleaned and baked to ~ 200° C prior to installation. Careful backfilling and purging with dry nitrogen is used during the assembly and servicing of the vacuum system. The system has not been baked since installation, but it has been backfilled to dry nitrogen several times. The base pressure is 2×10^{-9} torr and rises to 8×10^{-9} torr with 50 mA of electrons stored at 3.0 GeV.

Ionization gauges and fast sensors[6] are used to detect leaks and desorption diodes[7] sense contamination. These devices are monitored by a vacuum control system which causes valves to close automatically in the event of vacuum problems. Fast isolation from SPEAR is provided by a vane which closes in 30 msec.[3] Under certain conditions (e.g., water-cooling failure) the SPEAR beam is also dumped. Fig. 5 gives a block diagram of the vacuum control system.

The vacuum system and vacuum control system have functioned well since operation was started in May, 1974. No significant leaks or contamination problems have been observed.



VACUUM CONTROL SYSTEM

Fig. 5

Radiation Shielding and Personnel Protection System

To maximize accessibility to the radiation, shielding and a personnel protection interlock system were designed to permit access close to experimental equipment during all phases of SPEAR operation (filling, storing and dumping of beam). Concrete, lead and steel are used in sufficient thickness to guarantee that the highest possible radiation levels in occupied areas under worst case accident conditions are < 25 rad/h. Radiation monitors are set to dump stored beams and stop injection when radiation levels in occupied areas exceed 100 mrad/h.[9] A permanent magnet at 5.5 m from the source deflects charged particles vertically so they cannot pass small vertical collimators and enter the SSRP building.

Protection against synchrotron radiation exposure is provided by thinner shielding (such as 1/8" steel sheets) adequate to attenuate the highest energy x-rays expected.

Access to the primary beam line area (along a tangent to the stored beam) is controlled by the SLAC operator in a standard manner used at SLAC. A pair of heavy shutters, each with redundant microswitches, must be inserted to block the beam before access is obtained. The SLAC operator logs the names of persons entering, observes the access on TV, and releases a key to open the door to the primary radiation area. All wiring to limit switches and key banks are in conduit used only for personnel protection circuits with the fewest possible cross connections within the system. Status panels are of the standard SLAC design. Telephone relays are used throughout and all circuits are hard wired.

Beam splitting mirrors and diffracting crystals placed in the primary beam generate secondary beams which enter areas from which there is no direct view of the stored electron beam. Each of these secondary beams passes through a pair of shutters and into a secondary beam experimental area in which most experimental equipment is located. Wherever possible shutter operation is made directly visible to give experimenters confirmation of proper operation. Secondary beam experimental areas are called hutches. Free space inside a hutch is inadequate for a person to be inside and still close the door. The problem thus becomes that of assuring radiation safety while providing convenient access to the interior of the hutch for purposes of setup and adjustment of instruments.

Early in the planning of SSRP decisions were made in conjunction with the SLAC Radiation Committee to implement a self-monitored radiation area access control program. That is, each experimenter is permitted access to his hutch by means of his own control and interlock panel without requiring further permission from outside operators and independently of the condition of other synchrotron radiation secondary beam runs or of the SPEAR ring.

The Hutch Control and Personnel Protection Panel was designed on the basis of this requirement. This unit affords the experimenter the following control:

1. Beam Stopper Open/Close.
2. Ion Chamber Reset. Parallel-plate transmission ion chambers downstream of shutters are used in x-ray beams (which are not enclosed in vacuum systems) to insure that shutters have blocked the radiation.
3. Hutch Key Release (under safe conditions).

In addition, there is an On-Line/Off-Line keyswitch, the key to which is kept by SLAC Health Physics. In normal operation (On-Line) all interlocks are activated. When, from time to time, a hutch is disassembled this switch is turned to Off-Line after precautions are taken, and in this state only the Beam Stoppers remain as active interlocks.

The Hutch Panel receives inputs from the Stoppers (IN or OUT of beam) from the Hutch Doors (OPEN or CLOSED) and from the Ion Chamber inside the hutch (OK or RADIATION ALARM). In addition, it keeps track of whether or not the hutch key is retained in the Solenoid Key Release Unit (a part of the Hutch Control Panel).

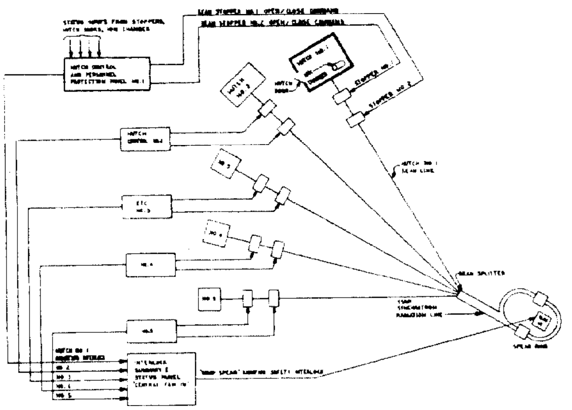
With this assemblage of status information from these external and internal sources, the Hutch Panel forms 2 separate and redundant interlock chains which, when violated (from, for example, Hutch Door being OPEN with radiation present or from several other possibly hazardous configurations) dump the stored beam and stop injection.

Similarly, the input status information is processed into a control signal which allows the experimenter to obtain the key to open his hutch door under safe conditions. If any of a number of unsafe conditions occur after this key is released, the Dump SPEAR interlock is tripped and the source of radiation eliminated.

The philosophy of design of the Hutch Panel embodies safety through redundancy. Relay logic (24 V) has been used throughout. Fail-Safety has been achieved by creating interlock violations from any of the following: loss of power, uncabling, blowing of fuses, malfunctioning of single switches (e.g., Hutch Door switches). Also, connectors are recessed so that electrical bypassing ("buggering") of interlocks is difficult.

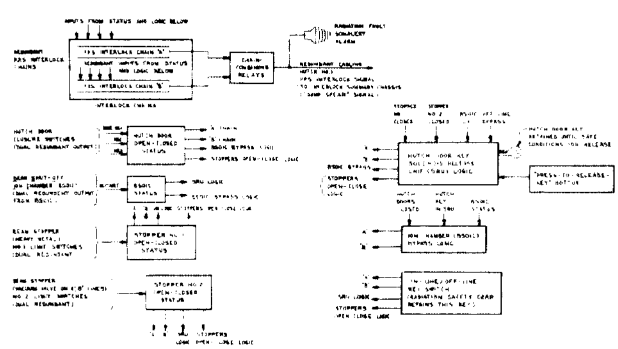
The accompanying figures portray the system in a hierarchical levels. Fig. 6 shows a schematized block diagram of the SSRP experimental areas and associated devices. Fig. 7 depicts the functional logic and status blocks which comprise the interlocking of the Hutch Control and Personnel Protection Panel, the heart of the self-monitored radiation access system. Fig. 8 shows the corresponding control block diagram.

This system has been in operation since May, 1974, and has performed as expected.



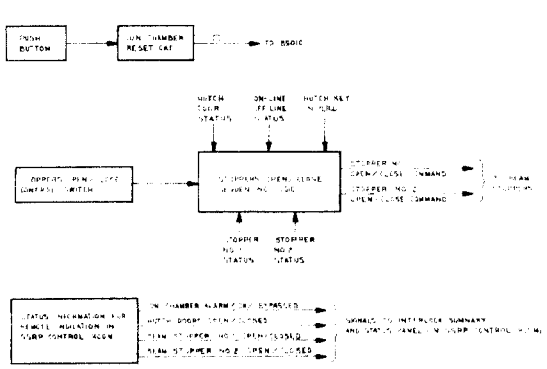
HUTCH CONTROL SYSTEM
OVERALL SYSTEM DIAGRAM

Fig. 6



HUTCH CONTROL SYSTEM
FUNCTIONAL LOGIC AND STATUS BLOCKS

Fig. 7



HUTCH CONTROL SYSTEM
SINGLE HUTCH CONTROL BLOCK DIAGRAM

Fig. 8

Orbit Monitoring and Control

The SPEAR beam is normally maintained within ± 3 mm of the nominal central orbit. In the radial direction this has been found to be adequate for position tolerance of the synchrotron radiation beam. In the vertical direction, however, only a small fraction of this is tolerable. The vertical opening angle of the synchrotron radiation ($\sim \frac{mc^2}{E}$) is $\sim .2$ mrad. Some experiments collimate to 1 mm at 20 m from the source point. A vertical orbit distortion of a fraction of 1 mm can result in a displacement of several mm at the location of an experiment because of the angles associated with orbit motion. Thus it has been found necessary to reproduce the position of the synchrotron radiation source point to a fraction of 1 mm.

This is accomplished by powering a pair of trim coils which provide equal horizontal dipole fields. These coils are located in quadrupole magnets which are 6.55 m upstream and 8.75 m downstream of the synchrotron radiation source point. Since they are approximately 180° apart in the phase of the vertical betatron oscillation these coils produce a local beam bump with only a small residual (~ 5% of the peak local distortion) around the rest of the ring.

At present the SPEAR operator centers the synchrotron radiation beam by TV observation of its location on an aligned screen located 21 m from the source point. Position monitors are now under development which will produce an electrical signal proportional to the vertical beam displacement. A feedback system on the power supply controlling the beam bump will then keep the beam centered automatically.

Since the synchrotron radiation beam is simply and accurately positioned, all experiments merely align their equipment to accept a beam at the height of the SPEAR median plane. No further adjustments are necessary.

Acknowledgments

The successful operation of SSRP and the speed with which it was designed and constructed is attributable in large measure to the excellent cooperation and support services provided by SLAC.

References

1. J. M. Paterson, Proc. IXth Int. Accel. Conf., SLAC, May 2-7, 1974, p. 37. Also, J. M. Paterson, Proc. Part. Accel. Conf., Washington, D.C., Mar. 12-14, 1975, to be published.

2. H. Winick, Proc. IXth Int. Accel. Conf., SLAC, May 2-7, 1974, p. 685. Also, published as SLAC-PUB-1439, June, 1974.

3. S. Holmes, A. Klugman, P. Kraatz, Appl. Optics 12, No. 8, p. 113, Aug. 1973.

4. E. Hoyt and P. Pianetta, SLAC TN-73-10, Sept. 1973.

5. M. Baldwin and J. Pope, SLAC TN-73-13, Oct. 1973.

6. E. Hoyt, W. Pierce (1964), unpublished.

7. E. Garwin, E. Hoyt, J. Jurow, M. Rabinowitz, Proc. 4th Int. Vacuum Congress, Apr. 1968, Manchester, England.

8. This fast closing vane is of the type used in the ISR at CERN and was kindly supplied to us by CERN.

9. G. Babcock and G. Warren in "The Stanford Two Mile Linear Accelerator," R. B. Neal, Editor, p. 805, 1968, W. A. Benjamin, Inc.