SSRL RF SYSTEM UPGRADE*

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Abstract

The Stanford Synchrotron Radiation Laboratory started its operation as a parasitic light source in 1973, becoming a fully dedicated user facility in 1992. A project was approved in 1998 to upgrade the storage ring to a third generation source. In order to sustain higher current in a tightly reconfigured magnetic lattice, it became necessary to upgrade the RF system from the present 5-cell cavity to four units of single-cell cavities to be powered by one high-power or two low-power klystrons. We present an overview of the upgrade project to be completed by the year 2002.

1 INTRODUCTION

The SPEAR (Stanford Positron Electron Asymmetric Ring) was originally built for high energy physics studies in early seventies, the two-mile linac being an injector. In 1990 a dedicated injector consisting of a RF electron gun, three sections of travelling wave linac, and a booster synchrotron was completed.

About two years later, SPEAR became fully dedicated synchrotron radiation (SR) facility. For a stored current of 100 mA at 3.0 GeV, one RF system was powered up to about 180 kW of RF power for 1.6 MV of gap voltage at the 26 MΩ ($=V_g^2/P_{rf}$) rated 5-cell cavity and 80 kW of beam power. There is also a twin system in a standby mode. The two systems are fully independent of, and equivalent to, each other.

The SSRL Booster synchrotron [1] accelerates a bunch of 10^{10} electrons from 100 MeV to 2.3 GeV at the rate of 10 bunches per second. The injection energy is presently limited by the White circuit. When the stored beam current reaches 100 mA, the beam energy is ramped to 3 GeV for user run. The injection energy will be raised to 3.0 GeV (at-energy). The RF system modification needed for this change turns out to be minor.

At the SPEAR, the major upgrade is in magnetic lattice from the FODO to a double bend achromatic (DBA) configuration in order to improve the beam emittance from 160 to 16 nm-rad. This entails bending radius reduction from 12.47 to 7.858 m, thus increasing the SR power by 63%[2]. This additional loss must be compensated for by higher RF power. The contribution from the insertion devices remains the same since the beam energy stays unchanged at 3.0 GeV. This insertion device term increases slowly over time when new wigglers and undulators are added on. Therefore, the RF power capability must not be a limiting factor for some years to come in the overall light source operation.

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2 RF SYSTEM DESIGN CRITERIA

The SPEAR has 11 beamlines including the latest one undergoing a commissioning process. In order to preserve the configurational integrity of those beamlines, or to minimize the changes in the source points, the storage ring circumference must be essentially fixed. This puts a constraint in RF frequency choice. One obvious option is to keep the present frequency of 358.54 MHz, but there is no existing single-cell cavity design at that frequency. Any cavity at wrong frequency must be scaled. In this case, it is beneficial to follow the ones with the minimal frequency deviation from the SPEAR so that the extent of modification is rather minor, and the risk of introducing some unexpected higher-order modes (HOM) is reduced. For this reason the APS-type cavities operating at 352 MHz were extensively studied for their possible adaptation to the upgraded SPEAR RF system.

At the APS cavity[3] HOM's are picked up by the E- and H-type coaxial probes, go through a high-pass filter to contain the fundamental mode (FM), and get dissipated at the matched loads. Those probe-filter-load assemblies are to be added on as the stored beam current is raised and the HOM power is thus increased. This scheme of the HOM damping is yet to be perfected for reliable operation and effective out-coupling of HOM's.

The second candidate considered was the KEK Photon Factory (PF) type cavities[4]. They have nose cones for higher shunt impedance, and larger size beam pipes for the HOM's to spill out, then damped by two silicon carbide loads. These loads are circular cylindrical pipes inside the beam pipe, at some distance upstream and downstream of the cavity so that the FM power level there is sufficiently low. This way, the shunt impedance of the FM is preserved. From the SPEAR point of view, however, the longitudinal length of the cavity is too long to fit into a long straight section of the ring. Another

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point of concern was that the HOM damping at the beam pipe may have to be supplemented by the APS-type dampers as the stored beam current reaches the design maximum.

Finally a decision is about to be made to use the PEP-II single-cell cavities[5] without frequency scaling or other modification. The PEP-II cavity has three waveguide loads for HOM damping. The PEP-II low energy ring (LER) stores up to 2.25 A of positrons at 3.1 GeV, while SPEAR 3 will have 500 mA electron beam at 3.0 GeV. For SPEAR the cavity is over-built by a large margin, but it provides ample room for the future growth. The following sections will describe how these cavities will be installed and operated.

3 RF SYSTEM PARAMETERS

The table below shows the comparison between the present (SPEAR2) and upgraded (SPEAR3) RF systems and the beam parameters.

Table 1. Changes in beam and RF parameters

Parameter	Unit	SPEAR2	SPEAR3
Beam Energy	GeV	3.0	3.0
Beam Current	mA	100	500
Bend Radius	m	12.47	7.858
SR Power	kW	57.5	473
Power from ID*	kW	15.4	75.0
Energy loss/turn*	MeV	0.73	1.12
RF frequency	MHz	358.54	476.35
Harmonic number		280	372
RF voltage	MV	1.6	3.2
Cavity type		5-cell	single-cell
Number of cavities		1	4
Shunt impedance	MΩ	26	31
Cavity wall loss	kW	100	330
Beam power	kW	73	570

*With insertion devices as of 1999

Presently one 400kW-rated klystron powers the cavity at less than half the rated maximum. In SPEAR3 the RF power is close to 1 MW, which can be generated by two units of 500 kW klystrons or by one 1.2 MW klystron. For the low power klystrons existing power supplies can be used, whereas the high power tube needs 95 kV power supply for a 2 MW of DC power.

RF Power Balance

The PEP-II cavities were designed to dissipate up to 120 kW of wall power. At 7.8 MΩ the maximum gap voltage per cavity is 0.96 MV per cavity. The operational limit was set at 330 kW for 3.2 MV over the four cavities in order to prevent multipactoring at the cavity. As shown in the Table 1 above, the total RF power needed is about 900 kW for 500 mA stored current.

The reflected power from the cavity can be minimized at the maximum current by optimizing the coupling factor. Doing so, however, will change the RF characteristics of the cavity assembly that includes waveguide network. Since the reflected power will be only less than 1%, the coupling factor of 3.6 will be left unchanged. Taking the losses at waveguide and reflected power into account, the system still has some operational margin left for RF phase and amplitude control even with a 1.0 MW power source.

Unlike colliders, all the light sources have insertion devices (ID's) that grow in number and intensity over the years. The SPEAR has 18 straight sections available for ID installation: 16 are short (4.5 m), 2 are long (6.5 m). Presently there are seven sections occupied by ID's of 2 meter length each. Their rms magnetic field strength is 1.5 T on average. Let the klystron output power be P_k in kW and αP_k be delivered to the cavities of total shunt impedance R_s in MΩ. For total RF voltage V_g in MV, the cavity wall loss in kW is $1000V_g^2/R_s$. When the remaining power drives a beam of E GeV through insertion devices of total length L meters with magnetic field of B Tesla, the maximum current at SPEAR3 is

$$I\,(\mathrm{A}) = (\alpha P_k - 1000V_g^2/R_s) / (11.26E^4 + 0.633E^2B^2L)$$

For the beam energies of 3.0 to 3.6 GeV, and for the ID lengths of 12 to 36 meters, the maximum current possible is show on the Fig.1 below.

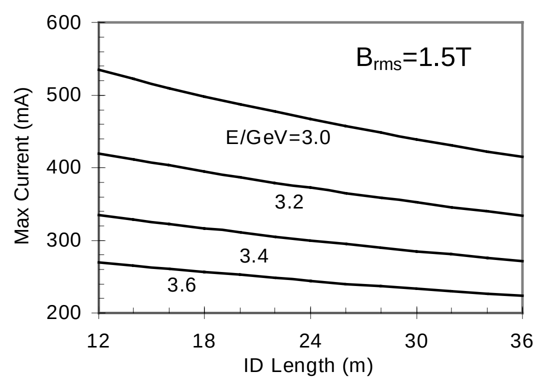

Fig 1 The maximum current possible in SPEAR 3 as a function of total insertion device length, with 4 cavities driven by 1.0 MW RF power for higher beam energies.

With 2 units of 500 kW klystrons, it is still possible to sustain 500 mA current, but the maximum power capability will be reached within a few years as new ID's are added to the existing ones. After this point is reached, either the current is reduced, or the RF voltage must be lowered at the expense of the beam lifetime.

System Configuration

The high power systems of klystron, circulator, wave-guide, magic-T's, and cavities are configured as shown in Fig. 2 below.

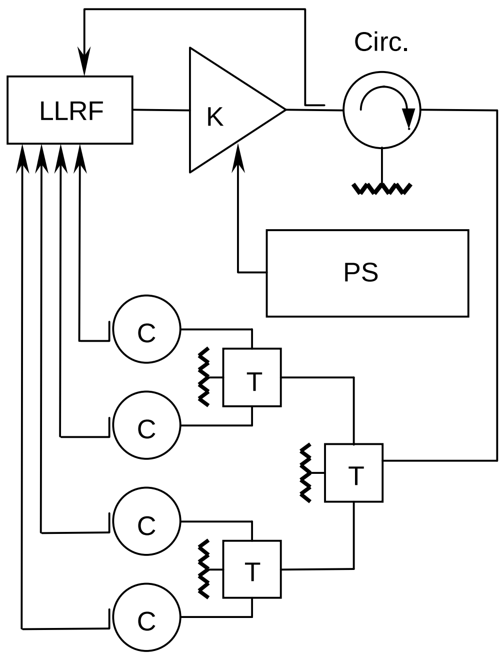

Fig. 2. Block diagram of the SPEAR3 RF system showing the low-level RF (LLRF), klystron (K), power supply (PS), circulator (Circ.), magic-T (T) with high-power matched loads, and cavities (C) with RF probes.

One loop across the klystron is to compensate for the RF phase ripple caused by the power supply. The probes at each cavity are for feedback control of RF phase across the cavity through the movable tuners. The inter-cavity power balance and phasing are realized by matching the waveguide network. They are not in the control loop. When the RF phase between the nearest cavities is $2(n\pm0.25)\pi$, any reflected power from the two cavities are dissipated at the magic-T load upstream of them. If the relative phase deviates from this value, some portion of the reflection reaches at the circulator load. The LLRF also contains master oscillator and control circuitry for gap voltage, RF phase angle as well as RF parameter displays and interlocks. The basic setup of the LLRF will be modeled after the PEP-II. The effect of a small difference in RF frequency is negligible both in LLRF and in high power systems.

Timing

Since the Booster frequency will remain unchanged at 358.54 MHz, the SPEAR and Booster must share a common base frequency of 476.3361/93=5.121894MHz which is multiplied by 70 for 358.5325MHz of Booster frequency through phase-locked loops. This is to preserve the injection efficiency.

Cooling System

As the 5-cell cavities are replaced by single-cell ones and four water loads are added at the circulator and magic-T's, the cooling water demand is increased beyond the existing facility can supply. Four single-cell cavities will take 320 GPM of water with temperature regulation of better than $\pm$ 0.1°C for the beam stability. The water loads are not precision tuned in frequency so that there is no need for temperature regulation, but the flow must be sufficient for high power. Some additive such as ethylene glycol is to be added to the circulating water for better absorption of the RF power. Klystron cooling requirement remains the same as in the SPEAR2 system. A stand-alone cooling tower will provide chilled water to cool the cavity water and load water through two separate heat exchangers. The supply temperature is to be regulated by using a 3-way valve where the return water from the cavities is mixed with chilled water from the heat exchanger. The mixing ratio is feedback controlled by a PID type controller.

4 PLAN FOR THE FUTURE

The RF system installation depends on available straight sections, which are influenced by existing and proposed beamline locations and magnetic lattice. From the RF point of view it is best to install all four cavities in one location side by side. The West pit, where the old MARK II detector was, is the prime candidate. Then comes a question of radiation shielding and size of the tunnel, and space available next to the cavity location for klystron and power supply, as well as the water system. All these issues will be addressed before the end of 1999. Then detailed engineering design will be made as to how all these high power systems will be installed and integrated.

Thus far there doesn't appear to be any problems of excessive difficulties associated with the proposed RF system. To insure the system reliability for the benefit of users, sufficient number of spares will be acquired for all the subsystems. By employing the system that is basically identical to the PEP-2, which is on the same site, it is possible to share the spare systems.

5 REFERENCES

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