THE SPEAR RF CAVITY CHARACTERIZATION AT STANFORD SYNCHROTRON RADIATION LABORATORY*

Sanghyun Park *and* James J. Sebek
Stanford Synchrotron Radiation Laboratory
SLAC MS 69, P.O.Box 4349, Stanford, California 94309

Abstract

At the SPEAR storage ring, the 3 GeV stored beam is driven by a five-cell π-mode standing wave cavity operating at 358.54 MHz. The frequency tuning and the field balance between the cells are feedback controlled by movable tuners at the end cells. Another cavity of the same type in the ring can be powered for higher beam currentin the future, but it is presently in a standby mode as a backup system. This idle cavity is also used to suppress the beam instability by manually positioning the tuners. For the purpose of cold tests, one PEP-I cavity is being prepared for the RF measurements.

1 INTRODUCTION

At Stanford Synchrotron Radiation Laboratory (SSRL), a 3.0 GeV electron beam is stored in the SPEAR, which stands for Stanford Positron Electron Accumulator Ring and built originally for high energy research in electron-positron collision, to provide bright X-rays for the users at 10 beamlines. At the top of the fill the stored beam current reaches 100 mA, diminishing to about 50 mA when it is dumped for a refill 24 hours later. As an indication of the quality of the photon beam delivered, the intensity at every beamline is monitored.

A pair of photoelectric probes, made of tungsten tip and placed symmetrically at either side of the beam center, develops photoelectric voltage roughly proportional to the photon intensity at the center. The difference is used to steer the beam, and the sum is proportional to the stored electron beam current. Occasionally, however, the sum voltage shows spikes or bistable oscillations. From the users' point of view, this noise must be minimized by all means for them to do accurate measurements.

At the accelerator side, there are several factors that force the system to deviate from the designed way of performance such as higher order modes in the cavity initiated by the circulating beam, and fluctuations in cavity temperature mainly due to limits in cooling regulation. The stored beam current, photon intensity, cavity temperature as measured at one out of five cooling channels, and the positions of the two tuners #1 and #5 are shown below over a 2-hour period that includes 35-minute beam noise activities as seen at the beamline 10.

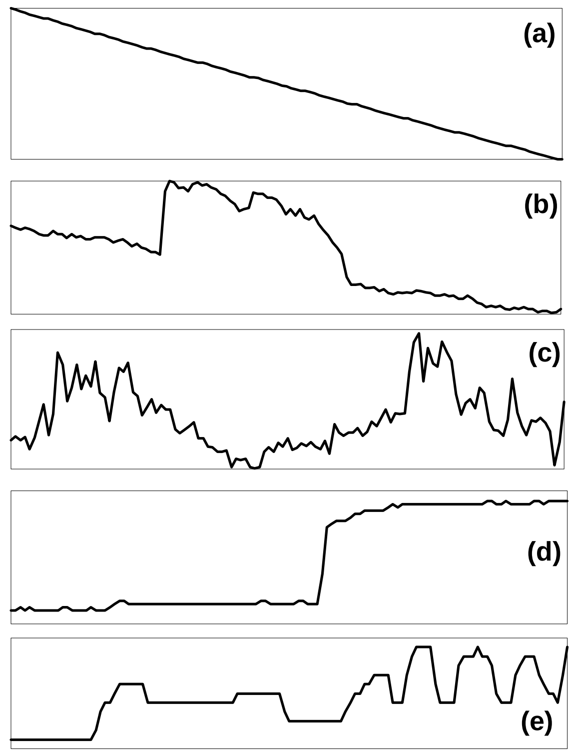

Fig. 1 Typical system performance over a two-hour period (horizontal axis) that includes a 35-minute beam noise. **a** beam current (96.2 to 90.6 mA), **b** Beamline 10 sum (0.13V span, 1.47V min.), **c** cavity temperature (between 48.4 to 48.9 deg C), **e** tuner #1 position (0.34 mm span), **f** tuner #5 position (0.11 mm span). All scales are linear.

From the figure above, it is clear that the stored beam current follows $\sim(1+t/\tau)^{-1}$ dependence even when the beamline 10 sum is jumped to its higher level, returning to the normal value about 30 minutes later. Without any loss

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of the beam, there is no discernable precursor detected in any data channel. It is noticeable that the period of noise coincides with a dip in the cavity temperature, and the noise subsides as the tuner number 5 makes a large excursion. In recent years, there are more data acquisition channels being added to the system for engineering and environmental diagnostics. Further details will be given in the later sections.

2 CONVENTIONAL CONTROL

There are a number of five-cell cavities currently in use worldwide mostly operating at 352 MHz. One such system is the PEP-I, now being replaced by single-cell based PEP-II for the B-factory at SLAC. Other examples are ESRF and LEP where the two tuners are placed in cells 2 and 3, instead of 1 and 5 at PEP-I and SPEAR.
The SPEAR cavities are scaled version of the PEP-I, and most low level RF and control/monitoring electronics are derived from the PEP-I design.[1] Despite the minor difference in operating frequencies, there are still many features that are common to the two systems.

At the SPEAR RF cavity, each cell is equipped with an RF probe, which indicates the accelerating field strength at the power level of 50 dB down from the driving RF power fed to the third cell. There are five voltages overall from the cavity; V_1 to V_5. The difference $\Delta = V_5 - V_1$ is used for differential movements of the tuners 1 and 5 so that $\Delta=0$. The sum $\Sigma = V_1 + \ldots + V_5$ is the readback voltage for the gap voltage set. As the gap voltage is raized from 0 to a set voltage of 1.6 MV or so in the absence of any beam, about 100 kW of RF power is dissipated at the wall. As a result, the temperature difference between the inlet and return ports of the cooling water channels are also raised to a value determined by the power dissipation along the cooling channel, and by the inlet temperature. As the electron bunches are injected up to100 mA, an additional 0.75 kW/mA is needed to make up for the beam loading.

The probe signal from the cell 3, across the high power RF input coupler, is also used as a reference for feedback control of the RF phase. Throughout the system, the control and monitoring circuitry is blind to any higher order mode. In fact, every detector is preceded by a low pass filter with the cutoff frequency at
400 MHz.

3 INSTABILITIES

During the startup period following a shut down for maintenance lasting two to three months, the system reveals higher ring vacuum pressure and shorter beam life time. Since the beam current needs to be 50 mA or higher to deliver useful photon beams to the users, the ring is filled twice or even three times a day until the ring vacuum is stabilized and the beam lifetime reaches
25 hour or so. As the lifetime is inversely proportional to the beam current, the vacuum quality defined as the product of the two is roughly a constant over many days, improving on a time scale of weeks.

The noise and fluctuations of the photoelectric detector voltage mentioned earlier are more frequent in this early phase of the startup. Even many months into the user run, sporadic occurences of this phenomena is noticeable
to the users. A fine adjustment of tunes, slight changes in manually set gap voltage, and repositioning of tuners at the idle cavity are the routine counter measures for stabilization.

As the ring is filled and some 40 bunches of electrons pass through the idle cavity, the wakefields are picked up by probes. After the filtering and amplitude detection,
the sum of all five signals is registered as a gap voltage. Again, only fundamental frequency component of the fileds is registered. Without altering this gap voltage, a small change in tuner position (fraction of a millimeter out of a 10 cm full range) results in a big variation of the tune space and the beam quality.

Recently it has been noticed that the brief beam noise that last only a few minutes occurs once a day, typically right after the sun rise. Considering the fact that relatively long (over 30 feet) waveguide is directly exposed to the sun, and the RF cables are not shaded either, the cause may well be thermal effect from the environment.

So far most of the efforts to maintain the noise-free beam have been based on empherical know how. And part of the justification for this study of the old cavities is to explore the parameter space in RF mode structure
as a function of externally controlable variables. The other part the goal is to address the physics and engineering issues centered on the use of the five-cell cavities at higher beam current with increased gap voltage to serve more synchrotron radiation users at additional beamlines with insertion devices in the future.

4 REVISITING THE OLD CAVITIES

At the time when the five-cell standing wave cavities were designed and built, the accelerator physics infra-structure was such that test equipment or computer codes were not powerful enough to provide details of the field structure or beam dynamics.

As a national user facility that delivers beams 24 hours each day interrupted only by injection that lasts about 20 minutes, the access to the SPEAR cavities is extremely limited, whether it’s active or idle. One alternative is to monitor the cavities with the beam on. Especially during the machine physics sessions, any desired number of bunches can be stored and one can afford to lose any or all of the beam over the course of machine exploration.

The raw signal from the cavity probe is coupled out before it reaches the low pass filter of the system. The insertion loss of the wide band directional coupler is compensated for by raising the detector gain, leaving the high frequency probing transparent to the rest of the system. A computerized data taking is presently under way to evaluate the effect of tuner positions on the beam behavior and high frequency components of the wakefields.

Still another option is to work on the cavity itself offline. The PEP-I cavity, decommissioned and surplused, was lifted to the SSRL booster building, with all of ancillary items attached to it still intact. Although the working frequency of the PEP-I cavity is 352 MHz, about 6 MHz below the SPEAR frequency, the basic structure is almost identical to the other. While it is not possible to run the electron beam through, one finds freedom in other areas. For example, there are eight RF ports available; one at the high power input coupler following the waveguide-to - coax adaptor, two on axis, and five RF probes. Any one port can be used for the reflection measurements, and any two can be selecterd for the transmission.

A modestly priced vector network analyzer is readily available. It has a frequency range of 0.3MHz to 3.0GHz and its dynamic range is about 70dB, which can be complemented by adding a wide band amplifier at each port. While a preamplifier that drives klystron can output up to 25 watts, its bandwidth is rather limited to about 400 MHz. For the study of higher order modes going up to 1.5GHz, a one-watt output amplifier covering the whole bandwidth of the network analyzer, commercially available off the shelf, can be modulated by a fast rising (less than 10ns) pulses for a time domain measurement.

Preparation is under way to make the tuner drive mechanism programmable. The electric probes have also been made to launch and detect test waves alng the cavity axis. Since there is no high power involved, wall dissipation and raised temperature distribution can be simulated by passing independently temperature contolled water through five separate water channels at very low flow rate. By placing adequate thermal shielding around the cavity, the accosiated electrical power requirement is minimal.

5 IMPLICATION TO THE UPGRADED SYSTEM

Unlike a case where a light source is designed with little constraint on machine parameters, the SPEAR has its circumference very much fixed. Although it is true that a small change may possibly be accommodated, the existing beamline locations dictate the geometry, and thus the RF frequency. Presently, the Booster[2] and the SPEAR have the circumference ratio of 4 to 7, and the SPEAR harmonic number is 280. If the frequency needs to be changed, both rings will have to be modified as well. Unless there is a compelling reason yet to be found, keeping the present frequency is the least expensive proposition. [3]

While many single-cell cavities are currently in use, or being planned at various installations, the standard design at either 500MHz or 476MHz is not entirely compatible with the SSRL system in straightforward way. One other drawback of the single-cavity system is that it has low shunt impedance. In the case of PEP-II low energy ring with 3.1MeV beam energy, which is quite comparable to the case of SPEAR, and more than 2000mA of beam current, the energy loss per turn is still lower as compared to the SPEAR when all the spaces for insertion devices are fully utilized. Yet, the low energy ring of PEP-II takes 3 MW of RF for its 6 cavities, whereas the fully loaded SPEAR with two five-cell cavities needs less than 600kW.

Once the measurements described above are made, the quantitative data will be utilized for the better simulation in system design and beam dynamics. With the data on optimal settings of tuner positions, for example, the latest version of MAFIA code may be beneficially used to elucidate the details of the field structure. Along with non-invasive measurements taken from the SPEAR cavities, both active and idle, the conclusion will me drawn as to the suitability of the present five-cell cavities for the upgraded beam parameters.

REFERENCES

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