

BUNCH-BY-BUNCH FEEDBACK KICKERS FOR SPEAR3*

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Abstract

SPEAR3 has a large cross-section copper vacuum chamber, mode-damped RF cavities and mostly low-impedance insertion devices. As a result, the beam is nearly passive-stable for 280-bunch beam currents up to 500 mA when the background gas pressure is low. In the future, more small-gap insertion devices will be installed and plans are underway to implement crabbing systems for short-pulse production. These requirements drive the need for a transverse bunch-by-bunch feedback system (BxB). In this paper we present plans for stripline kickers.

INTRODUCTION

SPEAR3 is a 3rd-generation storage ring with relatively low beam impedance [1]. From the outset, the copper vacuum chamber was designed to be 'passively stable' to thermal heat loads from a dipole radiation strike [2, 3]. The resulting high electrical conductivity coupled with large chamber radius (42 mm x 17 mm), shallow transition tapers, copper plating inside many of the insertion device chambers and mode-damped RF cavities also yields a passively stable electron beam that so far has not required bunch-by-bunch feedback.

As shown in Fig. 1, a 32 mm radius ceramic chamber with a single-turn winding has served as a diagnostic tune driver. By using Dimtel iGp12 front end electronics [4] and a spare PEP-II RF amplifier, feedback is possible in the range of 10's of MHz. The system has been successfully used to measure betatron tunes, for beam dynamic studies and to damp ion instabilities [5] but cannot damp higher-order multibunch modes or clear charge from closely-spaced bunches.

As the number of variable-gap ID chambers grows and SR research becomes increasingly susceptible to top-up injection transients, a wideband transverse bunch-by-bunch feedback system has become necessary. Trapped RF modes in the new ID15 vacuum chamber, for instance, can be seen in the beam spectrum [6] and bunch cleaning is needed for pump/probe timing mode experiments. A fast single-bunch driver will also provide a valuable tool for resonant crabbing studies [7] and in the future impedance induced by crab-cavities [8].

In total, the transverse BxB feedback system will utilize 1-cm diameter BPM button pick-ups, Dimtel feedback processors and 150 W RF amplifiers recovered from PEP-II.

* Work supported by US Department of Energy Contract DE-AC03-76SF00515, Office of Basic Energy Sciences.

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The kickers will be located in a 'diagnostic' straight section approximately 30 m from the amplifiers. Depending on the implementation, the initial kicker system can be relatively simple and cost effective [9].



Figure 1: SPEAR3 ceramic beam excitation module.

SOURCES OF INSTABILITY

The SPEAR3 vacuum chamber has inherently low coupling impedance but at 500 mA the beam spectrum has shown signatures of ion instabilities, resistive wall impedance and ID chamber resonances. By closing the loop on the BxB feedback system the beam motion can be brought under control.

Fast Ion Instability

Fast ion instabilities (FII) are the result of beam-gas interactions leaving ions trapping in the periodic potential of the bunch train. Ions in the head of the train can perturb bunches that follow. The effect is dominant in the vertical plane where transverse beam dimensions are small. Fast-ion effects have appeared in the SPEAR3 beam spectrum after venting and can be mitigated in part by using bunch trains with ion clearing gaps (Fig. 2) [5]. Due to the low-frequency nature of the FII, the motion is easily controlled with BxB feedback.

Resistive Wall Impedance

Transverse resistive wall impedance scales as

$$Z_{\perp} = \frac{2c}{\omega b^2} Z_{\parallel} \quad (1)$$

where

$$Z_{\parallel} = (1 - i) \frac{L}{2\pi b} \sqrt{\frac{\omega}{2\sigma}} \quad (2)$$

is the longitudinal impedance, L is the ring circumference, b is the chamber radius, σ is the chamber conductivity and ω is the frequency of interest. The SPEAR3 arc chambers have a vertical radius of 17 mm, high conductivity

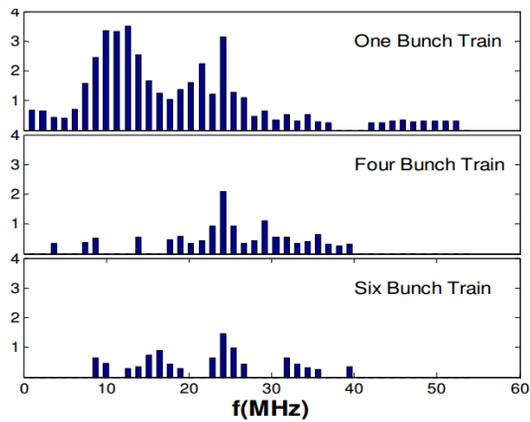


Figure 2: 500ma fast-ion instability in SPEAR3 as a function of bunch train number [3].

($5.9 \times 10^7 \Omega^{-1} / m^{-1}$ [2]) and consequently low resistive wall impedance [3]. Many of the original ID chambers also have copper-plated interior walls. With the addition of new, in-vacuum insertion devices, however, the resistive-wall impedance is increasing.

ID Chamber Resonances

A new 2-meter long in-vacuum insertion device (IVUN) for BL15 is currently being commissioned. The undulator period is 22 mm with 86 full periods to produce low energy photons. The ID gap can close to a minimum value of 6.82 mm with vertical beam instabilities observed at discrete gap settings [6]. Similar to observations elsewhere [10], the impedance is believed to include vertically-deflecting HOM modes in IVUN vacuum tank that are excited by the beam. Beam-based measurements have been made using the Dimtel front end electronics as a BxB mode analyser. As shown in Fig. 3, by scanning the ID gap from 6.82 mm to 8.6 mm in 10 μm steps, a series of unstable modes covering $\sim 100 \mu m$ gap movement and separated by $\sim 300 \mu m$ gap settings were found. The mode number and frequency of the modes range from 199.5 MHz for mode 156 to 205.9 MHz for mode 161. Numerical simulations using Omega3P [11] confirm the presence of HOM modes with high shunt impedance at the measured frequencies.

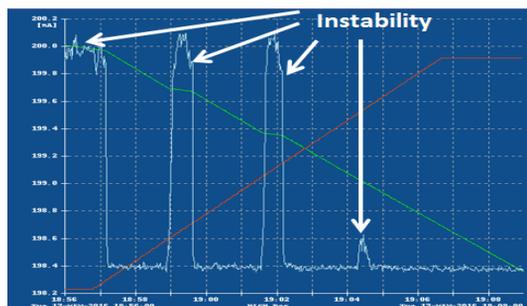


Figure 3: (white) spectral amplitude indicating unstable vertical betatron resonances at different BL15 gap settings (red).

KICKER REQUIREMENTS

Two important physical constraints for the stripline feedback kickers include chamber length and electrode radius. The most straight-forward SPEAR3 solution fits in place of the ceramic beam excitation module (Fig. 1) and has a similar radius of ~ 32 mm. X and Y stripline pairs can either be combined into one chamber or manufactured as separate units.

The striplines and feedthroughs must also tolerate high input power and be robust against beam-induced RF heating with up to 500 mA in different fill patterns and high single-bunch current. At the nominal 20 ps rms bunch length, the beam spectrum extends into the GHz range. For low-order mode suppression (FII, resistive wall) a modest drive power on the order of 10's of Watt is foreseen [12, 13]. To compensate for ID chamber resonances and generally help minimize chromaticity, the BxB feedback circuit should effectively decrease the passive vertical synchrotron radiation damping time by a factor of two or more. For bunch clearing applications the kicker bandwidth must extend to 238 MHz (476/2 MHz). Finally, for resonance crabbing studies the kicker needs to accommodate the full amplifier input power on the order of 100 W per stripline.

At the time of this writing, the initial plan is to borrow a spare kicker from the Advanced Light Source and rotate the striplines 45° with respect to the beam axis to enable simultaneous X and Y feedback (Fig. 4). The NSLS-II kicker design has also been considered to increase the beam deflection voltage. In this section we review the ALS kicker and the NSLS-II design. More aggressive kickers are considered below.

ALS Kicker

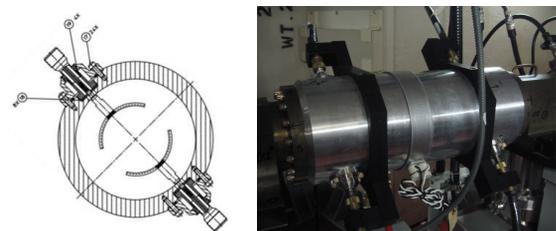


Figure 4: ALS kicker with 45° stripline rotation. The two kicker electrodes subtend 120° and the 37 mm electrode radius is 5 mm larger than the existing ceramic tube which simplifies SR masking.

The initial Fall, 2017 kicker implementation will use a single ALS stripline assembly axially rotated by 45° to provide feedback in both planes. The kicker has a shunt impedance of about 10 k Ω at DC and 4 k Ω at 250 MHz [14]. The 45° rotation will reduce these values by a factor of 2 [13]. Since the beam responds primarily at the high-Q narrow-band betatron frequencies, the feedback planes are strongly decoupled even with rotated electrodes. Similar to the ALS configuration, the X and Y feedback actuator signals will be

summed prior to the power amplifier to drive either one or both stripline electrodes.

Although the ALS kicker is designed for 500 MHz operation (30 cm striplines) only a small loss of shunt impedance is incurred at the 476 MHz SPEAR3 RF frequency and the shortened stripline extends the required bandwidth. The beam spectrum mismatch should not cause excessive HOM heating in the kicker chamber or feedthroughs. For reference, at the ALS a single 10 mA bunch couples 5W through the kicker terminals [14].

NLSL-II Kicker

An alternative approach that could be installed in 2018 is to use NLSL-II style kickers with higher shunt impedance [15] (Fig. 5). In this case the electrode radius is smaller (~25 mm) providing a DC shunt impedance of 14 k Ω and 6 k Ω at 250 MHz. Due to the smaller electrode radius and increased length of two back-to-back kicker chambers, the vacuum transitions and SR masking geometry would need re-design in the diagnostic straight.

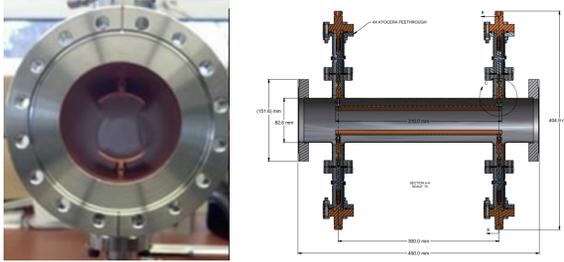


Figure 5: End and side views of an NLSL-II kicker with ~25 mm electrode radius.

With dedicated in-plane stripline assemblies and higher shunt impedance, more meaningful resonant bunch crabbing studies become possible.

KICKER ANALYSIS

Typical BxB feedback applications are readily satisfied with standard cylindrical stripline geometries. The most immediate requirement in SPEAR3 is to counteract ID vacuum chamber resonances. For this application, the net damping time should be about half the $\tau_y = 5.1$ ms vertical SR damping time. To estimate the stripline power requirement, the required voltage to damp betatron motion of amplitude ‘h’ in ‘N’ turns can be written

$$V = \frac{h}{N} \frac{2E}{\sqrt{\beta_m \beta_k}}, \quad (3)$$

where $\beta_k m$, $k = 9.4, 2.8$ m are the SPEAR3 betafuncion values at the monitor and kicker positions, and $E = 3$ GeV. Considering the number of turns $N = \frac{\tau_{\text{damp}}}{\tau_{\text{rev}}}$ as the ‘time to damp’, and using the relation $V = \sqrt{2PZ_s}$, the equation for kicker drive power becomes

$$P = \frac{1}{2Z_s \beta_m \beta_k} \left(2E h \frac{\tau_{\text{rev}}}{\tau_{\text{damp}}} \right)^2. \quad (4)$$

In Fig. 6 we plot the power requirement as a function of amplitude h for a high-frequency shunt impedance of 5 k Ω and an effective damping time $\tau_{y,\text{eff}} = 2$ ms ($N = 2564$ turns). For betatron amplitudes below 500 μm , the power requirement is modest. More realistic ALS kicker impedance values of 4 k Ω derated by a factor 1/2 for rotation and by 1/2 for single electrode excitation are indicated by the dashed line. A more complete analysis taking the BL15 HOM shunt impedance into account can be found in [13].

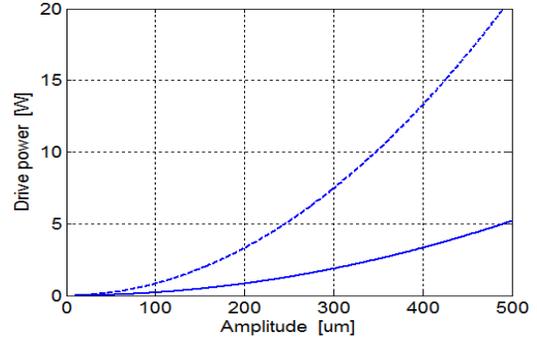


Figure 6: Kicker drive power as a function of betatron amplitude for $\tau_{y,\text{eff}} = 2$ ms damping time.

Future single-bunch resonant crabbing in the vertical plane will require considerably higher shunt impedance at full bandwidth. Preliminary estimates call for 300 μm vertical deflection in 100 turns [12] or $\Delta h = 3 \mu\text{m}/\text{turn}$ where

$$\Delta h = \frac{\sqrt{\beta_m \beta_k} \sqrt{2PZ_s}}{2E}. \quad (5)$$

For $\Delta h = 3 \mu\text{m}/\text{turn}$, the required beam deflection voltage $V = \sqrt{2PZ_s} = 3.67$ kV at 236 MHz. For a conventional stripline kicker with $Z_s = 5$ k Ω at 250 MHz the required power is $P = 1.3$ kW. More advanced kickers such as proposed for Sirius [16] can have shunt impedance of 30 k Ω at 250 MHz and would require $P = 225$ W at 236 MHz.

CONCLUSION

In the near term SPEAR3 plans to install a single ALS-style kicker module oriented at 45° to the beam axis to compensate low-frequency impedance effects, control ID chamber resonances and enable grow-damp studies. In parallel, a study will be made to investigate the need for a dual X/Y kicker configuration (e.g. NLSL-II) and/or the feasibility of installing a more aggressive high power kicker for resonant-crabbing applications.

ACKNOWLEDGMENTS

The authors would like to thank K. Baptiste, J. Byrd, S. DeSantis, S. Leemann, G. Portmann, D. Robin, F. Sannibale, C. Steier, and C. Swensen for technical assistance and loan of the ALS transverse kicker.

W. Cheng provided helpful advice for this work.

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