August 2, 2002

Proposal to the University Consortium for a Linear Collider

Proposal Name:

RF Beam Position Monitor for Measuring Beam Tilt

Classification (accelerator/detector: subsystem):

Accelerator: beam position monitor

Personnel and Institution(s) requesting funding:

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Collaborators:

John Corlett, LBNL
Marc Ross, SLAC
H. Henke, Technical University Berlin
Michael D. Hildreth, University of Notre Dame

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1 Project Overview

Controlling the beam emittance is important for future linear colliders as well as high-brightness light sources. There are two principal sources of emittance dilution in an X-band linac: transverse wakefields (from beam-to-RF-structure misalignments) and dispersion (from beam-to-quadrupole misalignments). Both lead to an emittance dilution that is correlated along the bunch length (*i.e.*, the tail of the bunch is deflected relative to the head). The ability to detect beam pitch or yaw is important in order to identify the primary sources of emittance dilution. For single beam bunches at an NLC, $2-15$ mrad beam tilt corresponds to 10% emittance growth. Detecting beam tilts in a few mrad range would also be useful for TESLA, future synchrotron radiation sources, and Free Electron Lasers.

Similar to inducing single-bunch tilts, transverse misalignments can also create intra-bunch position variations, such as "banana" effects (head-tail position differences) and "beam breakup" effects (tail instabilities). Maintaining high luminosity at a future linear collider requires compensation of such intra-bunch effects before the interaction point. Intra-bunch IP feedback systems being designed require measurements of beam position along the bunch train with precision of a few micros. Such feedbacks are needed for both warm copper and superconducting linear collider technologies. Also, since the overall size of the wakefield and quadrupole misalignment effects typically depends on the relative position of the beam centroid in accelerating or quadrupole structures, precise measurements of beam positions are needed along the length of the linac. For the X-band, the beam position along the linac needs to be measured with the precision of about 1 μm, while for the superconducting technology design the requirements are looser.

Resonant RF cavity beam position monitors[1] can be used to measure the average position of the bunch train with high precision, as well as determine the bunch-to-bunch variations. In a single-bunch mode, *i.e.*, in the mode where the time interval between the bunches is significantly larger than the fill time of of the cavity, the same cavities can be also used to measure the head-to-tail position differences, or bunch tilts. In the following section, we will briefly describe the RF beam position monitors and associated electronics, and outline the R&D plans for the cavity system.

2 Beam Position Monitors

A typical beam position monitor consists of three copper cavities, two (X and Y) cavities for monitoring the horizontal and vertical displacements of the beam, a Q cavity to provide an *in-situ* measurement of beam charge and phase. The position cavities are typically tuned to the quadrupole TM_{210} mode while the Q cavity uses the dipole TM_{110} mode. The BPMs constructed at SLAC in 1960s[1] use three independent cavities which are easy to manufacture and tune, although some new monitors use a single-cavity design which is more compact.

The resonance frequency of the cavities is typically a multiple of the carrier RF frequency. To achieve good position resolution and stability, the cavities are tuned to a high value of $Q > 1000$ which increases the resonant pickup. Custom RF electronics with I/Q demodulation[2] provides information on both amplitude and phase of the beam-induced signals. Measuring both amplitude and phase of the RF signals reduces systematic effects and increases position sensitivity. Figure 1 shows the schematic of the BPM processor.

Resonant RF BPMs with the custom electronics similar to what is shown in Fig. 1 have been successfully used in experiment E158 at SLAC. The cavities used in the test were standard SLAC linac cavities tuned to 2856 MHz, the carrier frequency of the SLAC linac. In the series of beam tests in the ASSET region at SLAC in 1999 and 2000, the pulse-to-pulse position resolution of better than 500 nm was achieved with dynamic ranges of $0.5 - 1$ mm

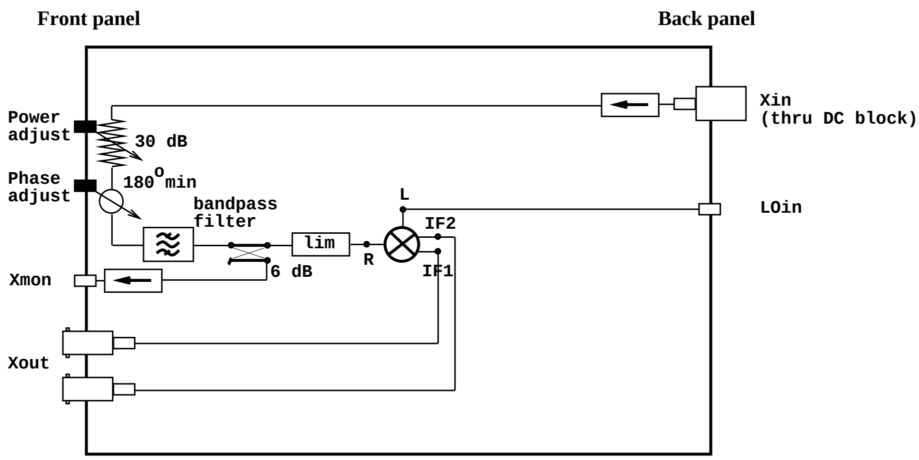

Figure 1: Schematics of the custom BPM signal processor.

for ~ 300 ns bunch trains. The phase resolution was about 0.5^o.

3 Beam Tilt Measurement

The main objective of this proposal is to demonstrate that the RF cavities can be used for measuring small tilts of individual beam bunches. This can be done by measuring the imaginary part of the beam-induced RF pulse, or a phase difference between the RF signals from a dipole and Q cavities.

A short beam bunch of charge q centered the distance x_0 from the electrical center O of the cavity (point O in Fig. 2) induces an RF pulse with voltage

$$V(t) = Cqx_0 \exp(j\omega t) \tag{3.1}$$

where C is a calibration constant, ω is the resonant frequency of the cavity, and time t is computed from the time the center of the pulse passes through the cavity. If the bunch is pitched by amount δ from head to tail, the RF voltage is instead

$$V(t) = Cq \exp(j\omega t) \left[x_0 - j\frac{\delta\sigma\omega}{16c} \right] \tag{3.2}$$

The beam tilt introduces a phase shift

$$\Delta\phi = \frac{\Delta x}{x_0} = -\frac{\delta\sigma\omega}{16cx_0} \tag{3.3}$$

equivalent to an offset of $\Delta x \approx 13$ nm for a typical beam size of $\sigma = 400$ μm and a tilt of $\delta = 2$ μm. For small offsets of $x_0 \sim 1$ μm, the phase shifts of $\approx 0.7^o$ should be measurable. It is clear that for this measurement the phase information is vital: it would be hard to

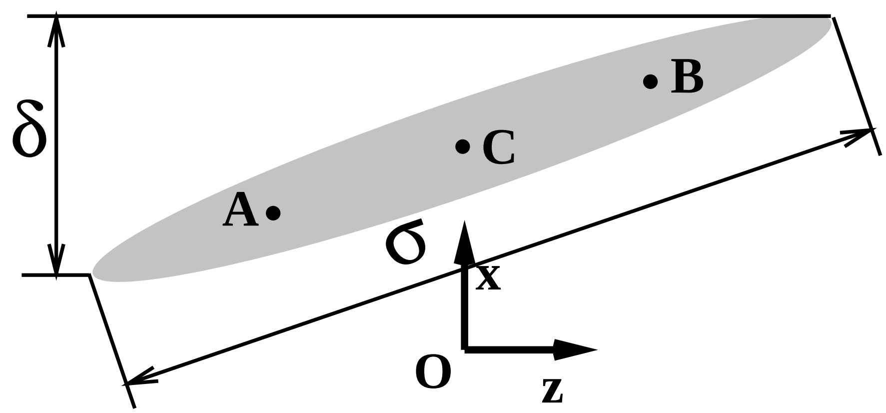

Figure 2: Tilt of the bunch relative to the **z** axis of the cavity.

extract the small offset from the amplitude signal alone (for example by measuring the RF power). For the phase measurement, the challenge is to be able to keep the beam centered at the cavity with high accuracy, and to be able to maintain the phase stability. The former requires being able to position the electrical center of the cavity near the beam axis (by either moving the beam or the cavity), and the latter requires precise temperature and environment control, as well as good cancellation of the dominant monopole mode in the dipole X cavity[2].

4 Scope of the Project

We plan to construct the high-frequency (X-band) cavity for position measurement with high quality factor Q and strong monopole mode suppression (for example by using symmetric outputs). In addition to suppression of the monopole mode, we must ensure that the degeneracy of the TM110 and the TE 010 modes is split, since the tilted beam also couples to the TE mode. The phase stability would be achieved through precision temperature control of both the cavity and associated electronics. We would assemble the I/Q demodulator electronics similar to the circuit shown in Fig. 1. The assembly and the electronics could be tested at SLAC ASSET area or at the KEK ATF facility.

The approximate cost for the cavity and electronics is $100k. The first year's involvement will be designing the cavity and electronics. We request a full-time graduate student for this effort. Another involvement in the first year will be to join SLAC staff members (Marc Ross et al.) for testing the concept of the tiltmeter at the KEK ATF facility. We request travel funds for working with them in Japan. The second year will involve fabrication of the cavity and electronics. Installing and testing the new cavity requires travel funds as well.

Item	FY 2003	FY 2004
Equipment	–	$100,000
Graduate Students	$25,000	$25,000
Travel	$10,000	$10,000
Materials and Supplies	$2,000	$2,000
Total	$37,000	$137,000

5 Cooperation

A proposal for the TESLA energy spectrometer by H. Henke (Technical University Berlin), located downstream of the detector, relies on a high precision microwave cavity BPM. The design of the spectrometer must include an analysis of beam tilt and angled beam trajectory effects. We intend to coordinate their design efforts with the tiltmeter R&D.

We also intend to coordinate our efforts with M. Hildreth (University of Notre Dame) who proposes the electronic and mechanical stability of a BPM-based energy spectrometer for the NLC.

References

[1] Z. D. Farkas *et al.*, preprint SLAC-PUB-1823 (1976).

[2] D. H. Whittum, Yu. G. Kolomensky, *Rev. Sci. Instrum.* **70**, 2300 (1999).