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Beam Position Monitoring System for the Proposed Asymmetric B Factory at SLAC*

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ABSTRACT

The beam position monitor system of the B Factory is drastically different from the actual PEP system. We present a description of the new configuration and list the features which have been adopted to make this system a highly reliable diagnostic tool.

An electrode geometry is suggested, based on the maximum-acceptable power extracted from the beam, and the measurement resolution is estimated by assuming some practical bandwidth and the noise level. Finally, an estimate of the system precision is made by adding up what is expected to be the most significant systematic errors.

1. INTRODUCTION

Pickup electrodes have been recognized to be an indispensable tool for commissioning and operating accelerators. Even if some machines have been running without electrodes or with an insufficient number of them, further improvements of these machines have usually been helped by a larger number of position detectors. Also, more stringent requirements for beam orbit control and also operation of strong focusing lattices and transport lines have both led to an increase of the number of installed pick-up electrodes.

Button electrodes are now very popular with electron/positron rings because they occupy very little Z-space. The two rings of the B Factory each have 144 beam position monitors (BPM), a number which amounts to one BPM per cell and to a little over five per betatron wavelength for the high-energy ring, and four for the low-energy ring.

In addition to button electrodes, it has been proposed that a higher-resolution position monitor be installed near the interaction region to help bring the beams into collision. Most likely, these electrodes will be strip line.

Present-day high-volume data processing allows for treating the large amount of information delivered by a multi-turn pickup-electrode system. Depending on the system organization, the processing speed, and the data handling, a BPM system can supply not only the single-turn trajectory and the stored-beam orbit, but it can also provide a measurement of the tunes, the phase-advance along the lattice, and the machine-dynamic aperture.

2. SYSTEM CONFIGURATION

To be able to offer the above-mentioned features, we plan to equip each pickup station with four high-quality transmission lines. This investment is mandatory if one desires a true single-turn system. Single-turn position measurement consists of acquiring a snapshot picture of the beam position when, because of some magnetic anomaly, the beam cannot be stored. In this case the beam travels either over only a fraction of the circumference, or maybe for a full turn, or even more, such as two, three, or four turns. As a result, the repetition rate of the signals to be processed is the injection rate of 60 or 120 Hz [1], but if successive turns are successful, the time separation for processing each turn becomes, of course, the machine period, or 7.2 μs.

By contrast to the single-turn system, the stored-beam system benefits from a much higher repetition rate, i.e., the bunch frequency, and processing can be done in a variety of ways. However, making measurements every 7.2 μs seems practical whether the machine is filled with one bunch or 1658 bunches. The electronics must accommodate these two modes of operation with flexibility, so that the abrupt transfer from one turn to many turns, and hopefully to a stored beam, can be met gracefully, without interruption of the beam monitoring.

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Although it is not the scope of this writeup to detail how the electrode pulses will be digitized, a likely processing scenario could consist of initiating a sequence of 1023 measurements for each station, at the machine revolution frequency, and repeating this cycle every 16 ms (the injector period). In this fashion, the beam orbit acquisition system becomes intimately related to the triggers of the injection system. Yet, it is not our intent to measure the position of individual bunches; however, the transverse feedback system [2] of each ring is designed to provide this information at one point, at least, on the circumference.

3. POWER COUPLED TO PICKUP ELECTRODES

The model used to calculate how much beam power couples to a button is the capacitive divider of Figure 1a, as it is excited by the beam voltage which appears as a train of delta functions of area $(2\pi)^{1/2}\sigma V_b$. The total power delivered to R_0 is obtained by summing up the power of all the Fourier components of $v_0(t)$. We also calculate the beam power coupled to a 15-cm strip (a length approximately equal to $\lambda/4$ at the RF frequency), and with a strip width taken to be the same as the button transverse dimension.

For this second model (Figure 2a), the induced beam current $\frac{Qe}{(2\pi)^{1/2}\sigma}$ is divided equally between the strip impedance R_0 and the signal cable impedance R_0.

Note that the total power delivered to the strip is five times larger than the one delivered to the button, and that the power at the RF frequency (476 MHz) is 70 times larger in the case of the strip. However, this analysis is likely to break down for the very high frequencies, say above a couple of GHz, since this part of the spectrum overlaps with the vacuum chamber waveguide modes. Also, the coaxial lines connecting these electrodes to the electronics present an attenuation proportional to $(n\omega_0)^{1/2}$ so a large amount of the spectra power is simply dissipated in these lines.

4. EXPECTED BEAM POSITION MEASUREMENT RESOLUTION

It is customary to estimate the resolution of a BPM system from the expected signal strength and from the Johnson noise level as they both appear at the detector input, before amplification.

We derive the signal strength from the above calculated power at the RF frequency (it is the lowest frequency if the rings had all their buckets filled) but, for a worse case estimate, we assume a beam current ten times smaller. We further reduce this signal by the amount of attenuation of the longest cables, a_c, and by the amount of the frequency conversion loss, a_f, which occurs in a heterodyne/homodyne circuit. If a wide-band processing were contemplated, a_f would then be the loss of the input-stretching filter.

Since a typical configuration of electrodes is needed for the evaluation of the resolution, we adopt the dimensions indicated on Figure 3. At the monitor center the sensitivity factor approaches $R/\sqrt{2}$ where R is approximately the radius of the circle fitted through the buttons' center (let us ignore the difference between horizontal and vertical sensitivity). We take R = 40 mm. The conventional relationship for the resolution of this BPM reads as follows:

$$\text{Resolution} = \left[F\frac{KTB}{2Pa_c a_f}\right]^{1/2}\frac{R}{\sqrt{2}}$$

F is the processing chain noise figure, $(4KTBR_0)^{1/2}$ is the *rms* Johnson noise *voltage* in the detection bandwidth B as measured across a matched load R_0, and $(2R_0Pa_ca_f)^{1/2}$ is the *peak* signal *voltage* at the amplifier input. Taking the typical values :

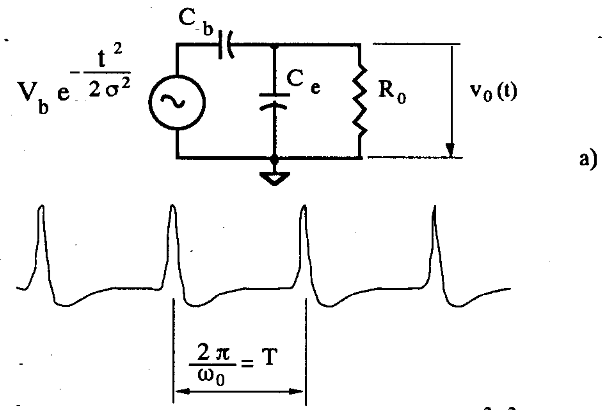
F	=	6 dB (a factor of 4)
KTB	=	10^{-10} mW @ 25 MHz and room temperature
P	=	0.05 mW (for 4 x 10^9 particles)
a_c	=	20 dB (0.010, for 800 ft of 3/8" Heliax)
a_f	=	8 dB (0.158)

we get for the resolution of a button-type BPM : *45 μm*

Repeating the calculation for the stripline BPMs of the interaction region with :

P	=	3.5 mW (for 4 x 10^9 particles)
a_c	=	7.5 dB (0.178, for 300 ft of 3/8" Heliax)

the resolution becomes: *1.2 μm*



$$P=\frac{1}{2R_0}\sum_1^{\infty}\left\{\frac{2}{T}\frac{Q_e}{C_e}\sqrt{2\pi}\,\sigma\,\frac{(n\omega_0\tau_e)\,e^{-\frac{(n\omega_0)^2\sigma^2}{2}}}{\sqrt{(n\omega_0\tau_e)+1}}\right\}^2 \qquad \text{b)}$$

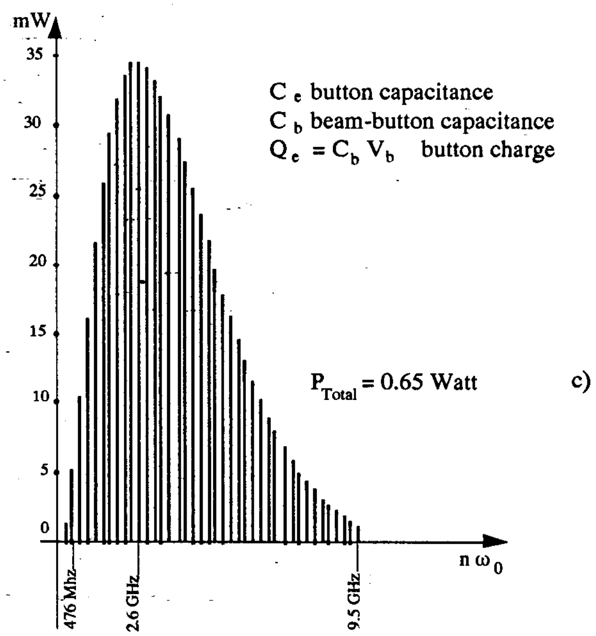


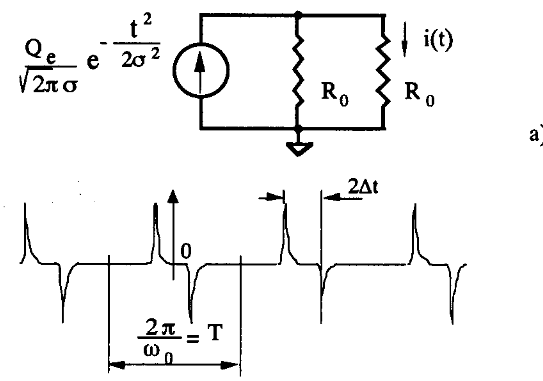
Figure 1 : Spectrum of the beam power coupled to a button electrode. Button diameter : 1 cm

R_0 = 50 Ω, T = 4.2 nS,

Q_e = 4% of the charge of a 4×10^{10} particles beam

C_e = 4 pF, $\tau_e = R_0 C_e$, $C_b \ll C_e$

σ = 33 pS. (bunch length : 2 cm)



$$P=\frac{R_0}{2}\sum_1^{\infty}\left\{\frac{2}{T}\,Q_e\,e^{-\frac{(n\omega_0)^2\sigma^2}{2}}\,\mathrm{Sin}(n\,\omega_0\,\Delta t)\right\}^2 \qquad \text{b)}$$

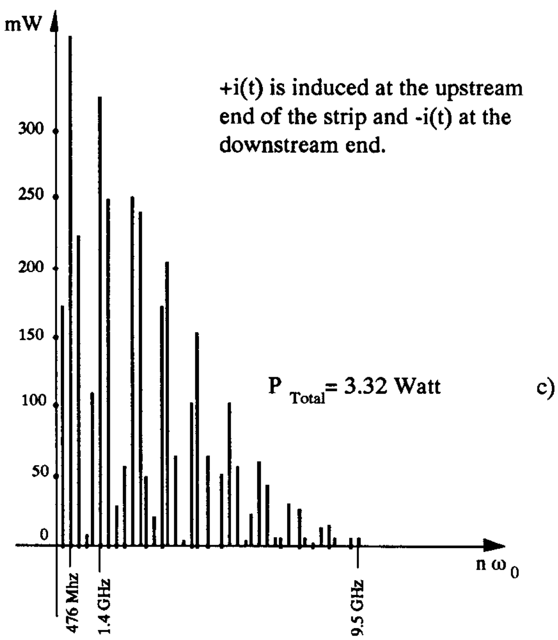


Figure 2 : Spectrum of the beam power coupled to a 15 cm strip. Strip width : 1cm

All other parameters are identical to those of figure 1.

Δt = 0.5 nS.

As the beam current increases, these values for the resolution are subject to improvements, provided that sufficient dynamic range be available without resorting to a front-end attenuator in the processing electronics.

5. EXPECTED BEAM POSITION MEASUREMENT ACCURACY

The evaluation of the absolute accuracy of a BPM system is much more difficult to assess. Contrary to the resolution for which a measurement can be repeated periodically, systematic errors are usually sorted once during the design and the initial tests. In principle one is only concerned with the residual systematic errors i.e., those which vary in such a way that they cannot be corrected. However, it has been a philosophy here at SLAC not to correct all known systematic errors, for fear of making worse errors (getting a sign wrong, for instance), and rather to work hard at minimizing them.

For completeness, and based on present experience, we list the errors which can be expected for a B Factory BPM system. All these errors are expressed as an equivalent beam offset, in microns, and for a typical monitor of the same variety as the one of Figure 3. Item 2 is highly reproducible and could, in principle, be corrected and replaced by the resolution achieved for this laboratory calibration (typically 10 μm). Item 6 could also be reduced by characterizing the electronics over several smaller beam-current ranges.

	μm
1. Monitor mechanical center to the quadrupole axis	50
2. Monitor electrical center to the mechanical center	100
3. Transmission lines attenuation match	25
4. Transmission lines phase match	neg.
5. Impedance mismatches @ 476 MHz	25
6. Calibration residue of processing electronics	150
7. Miscellaneous : timing, temperature, components, etc.	25

Adding up these errors quadratically we get: 200 μm

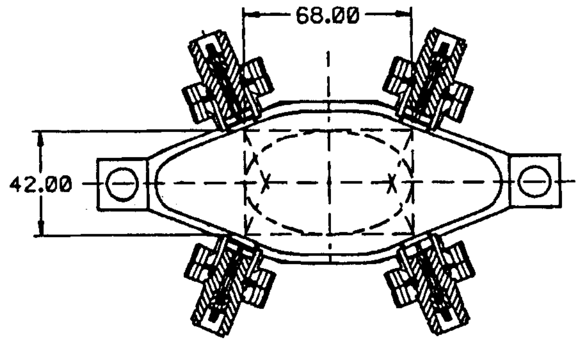


Figure 3 : Suggested Beam Position Monitor for the Low Energy ring. *(Sketch courtesy of Tim O'Heron)*

6. REFERENCES

[1] T. Fieguth *et al.,* "Injection System for the Proposed Asymmetric B Factory," SLAC–PUB–5775, March 1992.

[2] J. D. Fox *et al.,* "Feedback Implementations, Options and Issues for B Factory Accelerators," SLAC–PUB–5932, September 1992.

7. FIGURE CAPTIONS

Fig. 1. Schematic of the B Factory $e^{\pm}$ injection system, using the SLC linac and added bypass lines.

Fig. 2. Optics for the positron extraction, bypass line, connection to SIT and SIT (dispersion not shown).

Fig. 3. Stored-beam orbit during injection into HER. Applies also to LER with a change of scale.

Fig. 4. Phase-space diagram of injection acceptance for HER after chromatic correction.

ACKNOWLEDGMENT

It is a pleasure to thank Gary Godfrey for his interest in this system.