FAST BUNCH-TO-BUNCH CURRENT SAMPLING IN THE CORNELL ELECTRON-POSITRON COLLIDER

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Abstract

Preliminary studies of a high resolution Cornell Electron-positron Storage Ring (CESR) bunch-to-bunch signal processing system are described. In these studies, a prototype inductive-integrating, sampling current monitor is evaluated for improved estimation of bunch lifetimes over a series of planned CESR luminosity upgrades. Initial test data indicate significant performance advantages over conventional electrostatic pickup systems in the areas of linearity, dynamic range and beam position sensitivity. Novel features of the fast bunch current monitor include its wideband passive integrating pickup, diplex filter section and high resolution bunch signal processor (BSP). Evaluation studies in CESR indicate this fast bunch monitor is potentially useful in colliders and other storage rings utilizing bunch-to-bunch or bunch train separations down to 80 nanoseconds. Proposed system revisions to permit fast, high resolution bunch train current measurements in future CESR operations are discussed. Commercial availability of several principal bunch-to-bunch current monitor components is noted.

Introduction

Fundamental revisions of CESR storage ring operating procedure are presently under consideration for increased luminosity via multibunch-train HEP operation[1]. Preliminary investigations have demonstrated the utility of diagnostic techniques which provide accurate lifetime and reliable absolute charge measurements of individual trains. Applications for a CESR multichannel fast current monitor include injection studies, examination of differential loss near parasitic crossings and tune-up for high energy physics.

Accurate differential current measurements and lifetime prediction require current monitor signal-to-noise (SNR) performance not obtainable with electrostatic pickups, and absolute determination of bunch intensities demands linearity beyond the capability of conventional pulse stretchers. A series of evaluation studies[2] conducted at Cornell several years ago in collaboration with CERN's LEP Division demonstrated the potential utility for CESR of a high resolution wideband passive-integrating bunch charge monitor. Since that time, further research and development at CERN[3,4] and technology transfer to the commercial sector has led to evolution of several high performance standardized system components[5]. This paper describes a prototype system for CESR, based on these components, which is suitable for both multiple bunch and bunch-train measurements.

Evaluation Fast Bunch Processor System

A single-channel version of the proposed multichannel CESR fast bunch monitor (FBM), assembled for evaluation of principal components and initial diagnostic tests, is shown in Figure 1. Of principal interest are performance of the

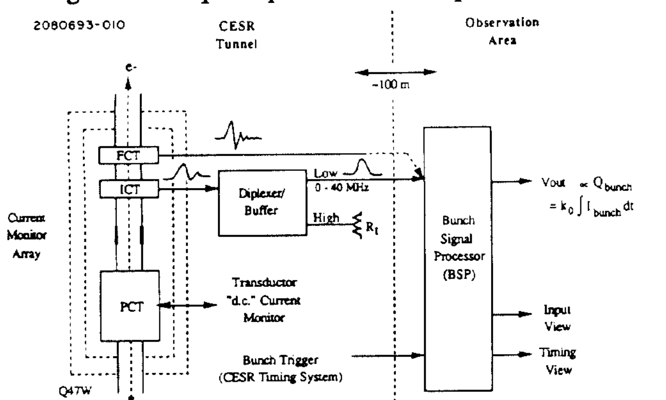

Figure 1. FBM evaluation system.

integrating current transformer (ICT), r.f. diplexer and BSP fast gated integrator subsystems. The ICT and BSP are commercial units (ref.: figure 2), while the r.f. diplexer is a proprietary lowpass filter device. For evaluation purposes, the prototype system's analog path is configured to resemble that of the proposed multichannel monitor, so that the ultimate dynamic range and linearity parameters of the proposed system may be accurately predicted by performance of the prototype. Only the ADC and I/O sections differ: for evaluation studies, a high resolution integrating voltmeter and

♦ Work supported by NSF grant PHY-9014664.

an IEEE-488 (GPIB) data bus have been substituted for the high resolution ADC's and CESR control system interface.

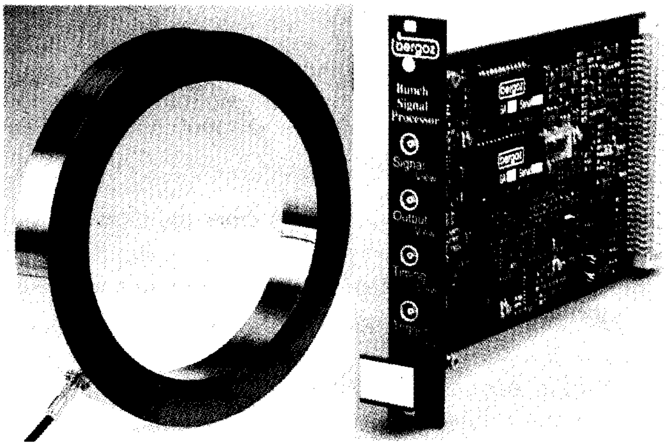

Figure 2. ICT and BSP system components.

As an electron or positron bunch traverses the CESR current monitor assembly, a fraction of its wakefield energy propagates through a capacitive gap in the ceramic beampipe section into a cavity which encloses the fast (FCT), ICT and PCT "d.c." current monitor transformers. Spectral components of the trapped electromagnetic field, in the range of d.c. to approximately 600 MHz, induce corresponding signals at the output of each transformer. The FCT output is a fast (.02 to 320 MHz @ -3 dB) single-turn diagnostic tool which can be used as a lower-resolution "backup" input to the fast bunch signal processing system if needed. For high resolution diagnostics, the spectrally-shifted ICT signal is required.

As a signal source for the fast bunch processor system, the ICT possesses a useful property of passive spectrum down-conversion[6], transposing essentially all energy deposited by a passing bunch to a lower frequency range. The translated spectrum is now entirely within the upper band limit of the bunch signal processors' (BSP) precision gated differential integrator, yielding optimal system dynamic range and linearity. System waveforms are shown in Figure 3. The ICT output waveform of Figure 3a consists of a spectrum-shifted (i.e., stretched) pulse of around 35 nanoseconds with a ringing artifact superimposed by a broad, unavoidable cavity resonance. All but a few percent of the wideband input energy has been translated into a signal bandwidth of ≈ 0.1 to 20 MHz. Figure 3b demonstrates the 35 MHz diplexer lowpass filter section's effect in removing the ringing component. Pulse width broadening from the original 35 nanosecond value to around 50 nanoseconds occurs in the filter, but has no appreciable effect on system performance. Figure 3c shows the timing sequence monitor signal available from the BSP bunch signal processor. Following a CESR timing system trigger, the processor first synchronizes, then initiates a signal integration period (70 nanoseconds for CESR), then integrates with opposite sign for a precisely equal time. In CESR, the desired bunch is acquired during the second timing window, with the corresponding baseline offset integral taken during the third window, after which the BSP resets to its quiescent state.

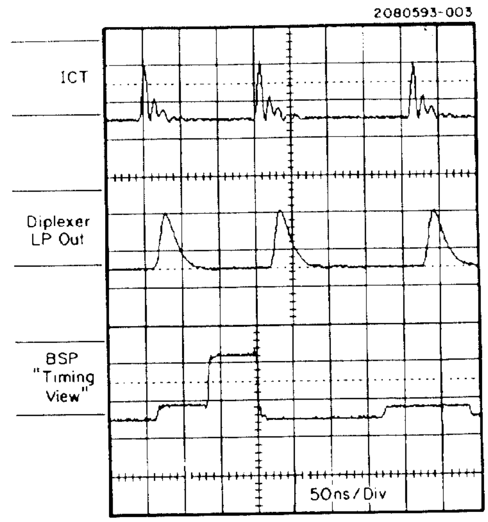

Figure 3. FBM signal and timing view waveforms.

Evaluation data

Signal-to-noise (SNR) performance, dynamic range and linearity are extracted from analysis of data collected at a fixed timing value. Results of the data analysis are presented in Table 1.

Resolution:	Q_{Nrms}	=	8.40E6	e
Maximum charge:	$Q_{max.}$	=	9.03E11	e
Dynamic range:		=	1.07E5	
Linearity:		=	1.47E-3	

Table 1. Measured parameters.

These measurements indicate a CESR fast bunch resolution of approximately 1.3 pC (0.53 μA)—very good performance for the 167 ms averaging period under which the evaluation data were taken (a factor of 1.5 improvement is expected with a 0.5 sec/point data input rate of the proposed multichannel system). Saturation bunch charge has been calculated from the data scale factor; the dynamic range figure is based on the system saturation level and the calculated resolution. An upper bound on minimum linearity is derived from an exponential fit to the full data set.

Position sensitivity is a critical parameter which can strongly affect system resolution, due to the large transverse noise inherent in circulating lepton beams. Although the high prototype system resolution of Table 1 indicates little or no position sensitivity, a study of large deflections in both x and y transverse axes was conducted over a full range of possible CESR beam position offsets to verify the observation under worst-cast conditions. From analysis of the data, we conclude that the ICT position sensitivity is less than 5×10^{-5} for a ± 10.0 mm deflection.

Proposed Systems

A proposed multichannel high resolution bunch-to-bunch current monitor for CESR is outlined in Figure 4. Its analog

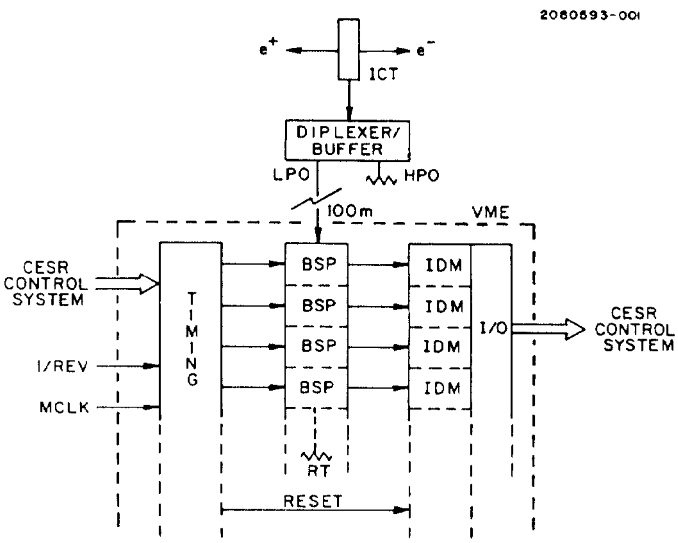

Figure 4. Proposed multichannel FBM

path is identical to the evaluation system, with the exception of signal division as needed for the parallel bunch signal processors. In the parallel system, triggers for the processors are generated locally and provision is made for interleaving (i.e., reassigning sampling times) as needed to best utilize the parallel BSP array. Interfacing to the CESR control system is effected through a parallel system of 20 bit integrating ADC's and a multiport control interface. All analog and digital subsystems will reside in a single VME crate.

In the near future, the multichannel system is expected to serve as a CESR multi-bunch train fast current monitor. Because the bunches in a CESR train will be separated by as little as 14 nanoseconds, the fast current monitor only provides charge integration over the duration of each of the 18 trains. This does not diminish overall diagnostic capability, however, since high resolution measurements of the integrated train charges will provide the same information regarding differential loss and absolute intensity as before. Nonetheless, it is evident that the BSP internal timing will have to be substantially modified to accommodate multibunch-train operation, since the trains are longer than the inter-train separations. We anticipate that appropriate scaling and weighting of BSP integration window intervals and values will provide a viable capability for future multibunch-train studies in CESR.

Conclusions

Analysis of evaluation data collected from the Cornell prototype fast bunch-to-bunch current monitor indicates that the critical performance parameters of dynamic range and linearity have been met at the present 180 nanosecond CESR bunch spacing. Position sensitivity has been found to be at or below the system noise level for beam offsets well beyond the maximum CESR aperture at the ICT pickup location. The multichannel fast current monitor, with some revisions, is expected to remain useful over a series of CESR multibunch-train upgrades. Compared with button or stripline based fast current monitors, the integrating current transformer (ICT)-based bunch charge monitor appears to offer far superior dynamic range, negligible beam position sensitivity and relative system design simplicity.

Acknowledgment

We wish to thank Messrs. J. Bergoz and A. Charvet (BERGOZ, Crozet, France), who provided us with expert technical assistance in preparation for the CESR evaluation studies.

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[6] K.B. Unser, "Design and Preliminary Tests...", p.2, §6.