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BEAM TRAJECTORY ACQUISITION SYSTEM FOR THE ARCS OF THE STANFORD LINEAR COLLIDER*

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1. Introduction

The Beam Position Monitoring system of the Collider Arcs constitute the main tool, along with the Moving Magnet system and the Backleg Windings, for controlling the beam emittance growth[1]. The two Arcs are analogous to two strongly focused transport lines[2].

The focusing and defocusing magnets can be rocked an amount of ± 1 mm at their upstream end as part of the orbit correction scheme[3]. This motion is in one plane only and, as a result, the BPM, which is mounted on the moving end of each magnet, is wired in such a way as to detect horizontal or vertical beam displacements only, depending on whether this BPM is attached to a focusing or a defocusing magnet.

This Beam Position Monitoring system is different from other BPM systems at SLAC, not only by the expense of its hardware (908 monitors, 500,000 feet of coaxial cable, over 20,000 connectors) but also by its ungated, self-triggered electronics. Moreover, it is the first time that we attempt to operate our BPMs with all the processing electronics installed in the accelerator tunnel.

2. Mechanical Design

The monitors are of modular design and are located in the 4.6 in. gap between each magnet. The electrodes aperture is 0.562 in. (14 mm) and their length to the short–circuit is 1.769 in. (45 mm). In the transverse plane, space is limited because of the four large bus bars (Fig. 1); for this reason, the monitor body is square and the feedthroughs are oriented vertically and are also elongated for access to the RF connectors. Studies were made of the amount of power that might be deposited on the electrodes as a result of a beam shower[4]. The temperature rise for stainless steel electrodes was unacceptably high, whereas for aluminum the maximum temperature remained below the annealing temperature. The four electrode assembly is screwed into a stainless steel end cap which is welded to the monitor body; before welding, the TIR run–out of the electrodes was adjusted to be less than 0.004 in. (100 μm). The connection between the aluminum strips and the center conductor of the feedthroughs is established by means of set screws.

Pumping of the system is done with ion pumps manifolded through the monitor body around the electrodes short–circuit.

The BPMs are held by guide rails on a non–adjustable support secured to the magnet end plate with dowel pins. Upstream, a set of stainless steel bellows establishes the continuity of the vacuum chamber with the use of miniflanges. Calibration of the monitors before installation was done, in a clean room, several times; the fixture measuring the coordinates of the electrical center showed repeatability of 10 μm. The histograms of Fig. 2 indicate the overall quality of the production. After installation, survey of the monitors location with respect to the nominal beam line yielded mean values of 60 μm for X, 80 μm for Y, with sigmas of the order of 25 μm.

3. System Architecture

Each Arc, North (e^-) and South (e^+), is served by 14 alcoves housing the instrumentation of as many as 40 BPMs (a span of 2 achromats). Therefore, it was convenient to break down the system into 28 sub–systems of 40 BPMs each. All monitors

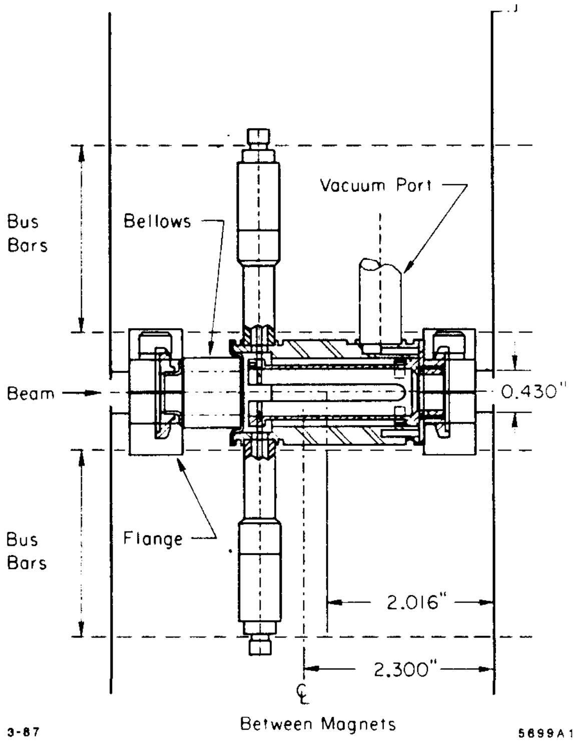

Fig. 1. Cross section of the monitor body.

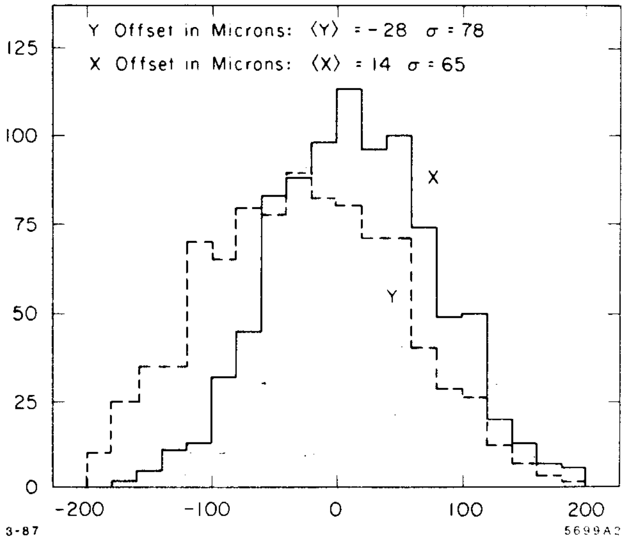

Fig. 2. Vertical and horizontal offsets for the production of 908 monitors as measured in the clean room.

are equipped with a set of 4 cables with lengths varying from 40 to 300 feet, depending on the location of the alcove with respect to the 2 achromats. This type of coaxial cable, RG 223, has been tested early in the project to check whether it would retain its timing and attenuation properties after being exposed to large doses of radiation. The electric length of the 4 lines has been trimmed to ± 0.1 ns, and their relative attenuation (in the

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band–pass of the detector) has been recorded, before and after installation.

Each set of cables is then connected to a quadruple low–pass filter and to two "adders" yielding a pair of signals which correspond to the beam position in one plane. Ten pairs of such signals (Fig. 3) are then multiplexed with Camac–controlled solid state switches[6,7]. One detection chain only (see the block diagram of Fig. 4) is therefore needed for each block of 10 monitors and since 4 such chains are operated in parallel in each alcoves, for each beam pass we can measure 4 beam coordinates at 14 locations along each Arc.

4. Electronics

The detector chain is a variation of our Linac electronics[8] with the modification allowed by single bunch, single plane operation, and improvements made to the front end and to the trigger circuit.

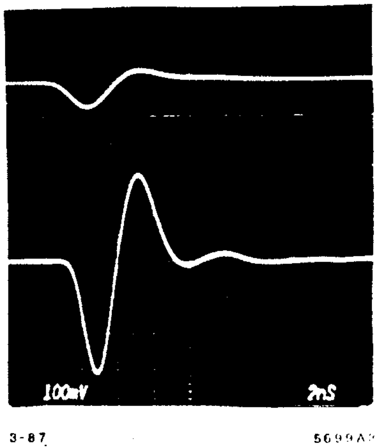


Fig. 3. Expected signal at the processor input for a bunch of 5 x 10^9 electrons, with long cables (top), short cables (bottom).

The two pick–up signals are stretched and amplified in a bandwidth of 1 to 50 MHz and their first peak is digitized whenever the previous data has been read and whenever a beam trigger is obtained. This trigger is derived from the zero-crossing of the waveforms of Fig. 3; its threshold is of the order of $1 \times 10^9 e^+$ or e^- for monitors with long cables, and it maintains its relationship to the bunch within ± 0.5 ns up to intensities of 1×10^{11} particles for monitors with short cables. A test pulser is installed in each Camac crate for the purpose of simulating the beam; it delivers calibration pulses of either polarity over a dynamic range similar to that of the pick-up signals.

5. Software for Troubleshooting, Calibration Research and Production Testing

One unified program written in TURBO PASCAL and running on an IBM-XT PC satisfies all three purposes. TURBO PASCAL offers graphics capabilities and a run–time package significantly smaller than that of FORTRAN compilers. The program KTNH operates with the IBM PC's function keys which are defined through various menus (Fig. 5). The hardware of Fig. 4, RF Head and TNH, is tested by running four calibration sweeps covering choices of e^+ or e^- pulses and High or Low TNH sensitivities. For each range of inputs the ADC's are read, the Pedestals are subtracted and the two channels' gain ratio is calculated. An intercept G_0 and a slope m are determined by linear fit (within cuts to avoid the ADC's saturation and the digitization errors at low count number). The equivalent offset of each processing chain is then found according to:

$$\text{Offset } (\mu\text{m}) = 6137\ (R1 - G * R2)\,/\,(R1 + G * R2)$$

6137 μm is the monitor slope

$R1$ and $R2$ are the ADC's readings less their Pedestal

$$G = G_0 + m * (R1 + R2)$$

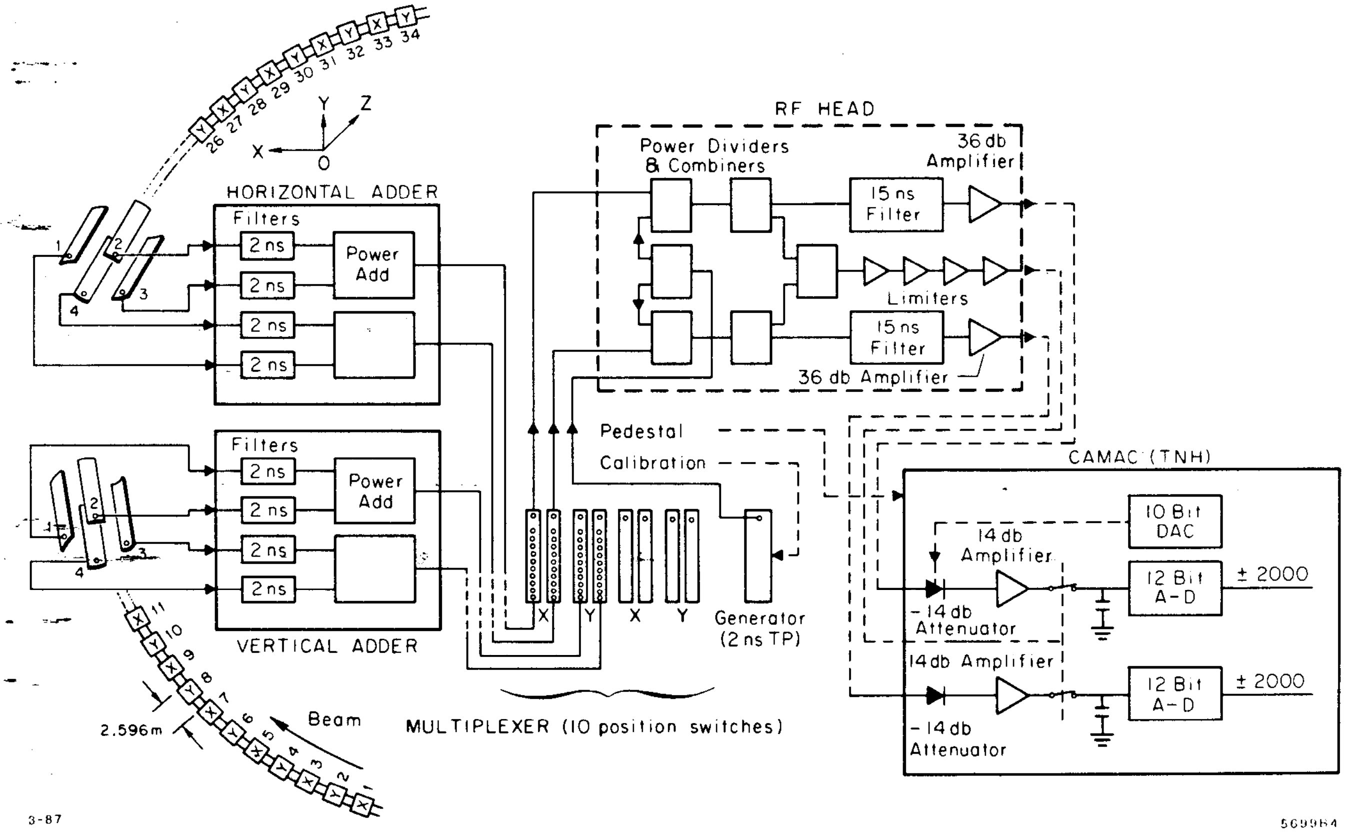
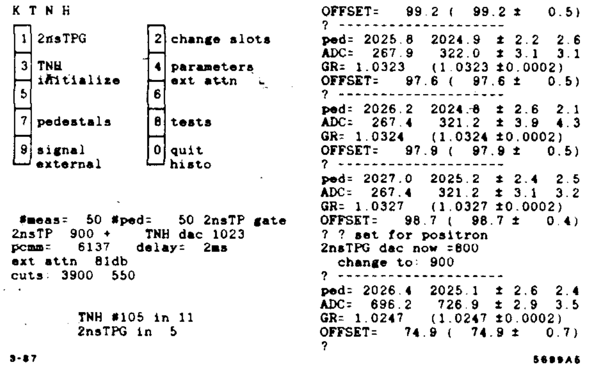


Fig. 4. System block diagram.

This is all done from a sweep sub-menu of KTNH which prompts the user for various set-up parameters and allows the resulting data to be filed, printed or plotted (Figs. 6 and 7).



```
#meas=  50 #ped=   50 2nsTP gate
2nsTP  900 +    TNH dac 1023
pcmm=   6137   delay=  2ms
ext attn  81db
cuts  3900  550

          TNH #105 in 11
          2nsTPG in  5
```

```
OFFSET=   99.2 (  99.2 ±   0.5)
? --------------------
ped= 2025.8  2024.9  ± 2.2  2.6
ADC=  267.9   322.0  ± 3.1  3.1
GR= 1.0323   (1.0323 ±0.0002)
OFFSET=   97.6 (  97.6 ±   0.5)
? --------------------
ped= 2026.2  2024.8  ± 2.6  2.1
ADC=  267.4   321.2  ± 3.9  4.3
GR= 1.0324   (1.0324 ±0.0002)
OFFSET=   97.9 (  97.9 ±   0.5)
? --------------------
ped= 2027.0  2025.2  ± 2.4  2.5
ADC=  267.4   321.2  ± 3.1  3.2
GR= 1.0327   (1.0327 ±0.0002)
OFFSET=   98.7 (  98.7 ±   0.4)
? ? set for positron
2nsTPG dac now =800
  change to  900
? --------------------
ped= 2026.4  2025.1  ± 2.6  2.4
ADC=  696.2   726.9  ± 2.9  3.5
GR= 1.0247   (1.0247 ±0.0002)
OFFSET=   74.9 (  74.9 ±   0.7)
?
```

Fig. 5. KTNH's main menu displays two windows for parameters and a larger window for user dialogue and test results.

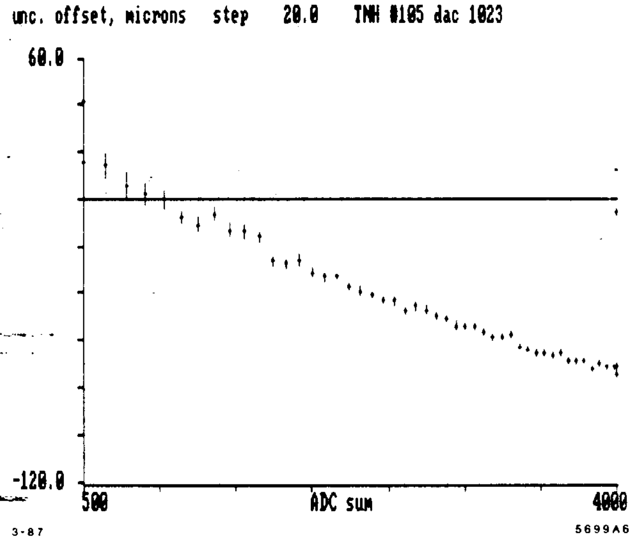


Fig. 6. Uncalibrated offset of a typical TNH. The maximum sum signal is approximately equivalent to 1×10^{11} particles.

6. System Accuracy

The absolute measured Beam Position depends on the precision of the clean room calibration, the survey of the monitors location with respect to the magnets, the relative attenuation measurement of the coaxial cables and the residual error of the electronics after calibration. All these parameters have been entered in the data base for the SLC Arcs. We believe that the above error budget does not exceed 100 μm rms. Yet the effect of the vacuum pipe on the measured signals, particularly the effect of the bellows which precedes the monitor's electrodes, is of some concern when it comes to absolute accuracy[9].

Conclusion

At the date of this writing we have monitored an electron bunch through the entire north Arc (450 monitors). Figure 8 shows the beam vertical position and the transmission (TMIT) or sum signal; TMIT will be later corrected with the cables attenuation and the relative gain of the four processing chains of each alcove, to present a smooth envelope.

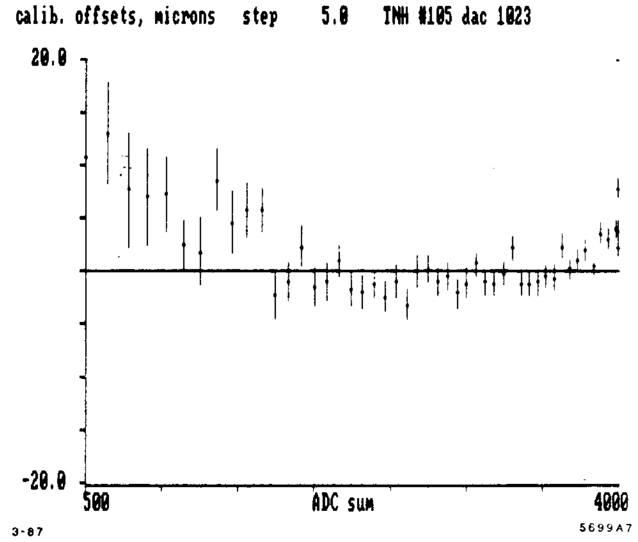


Fig. 7. Calibrated offset of a typical TNH after correction with the parametrized gain ratio. Same sum signal as for Fig. 6. The error bars give an idea of the resolution of the system.

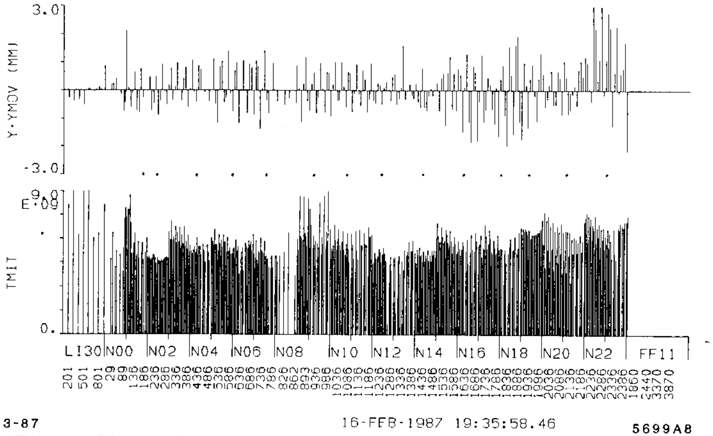


Fig. 8. Vertical position and transmission of the first 47 GeV beam through the 23 achromats of the north Arc. The dots indicate the location of the 14 alcoves along the machine.

Acknowledgments

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