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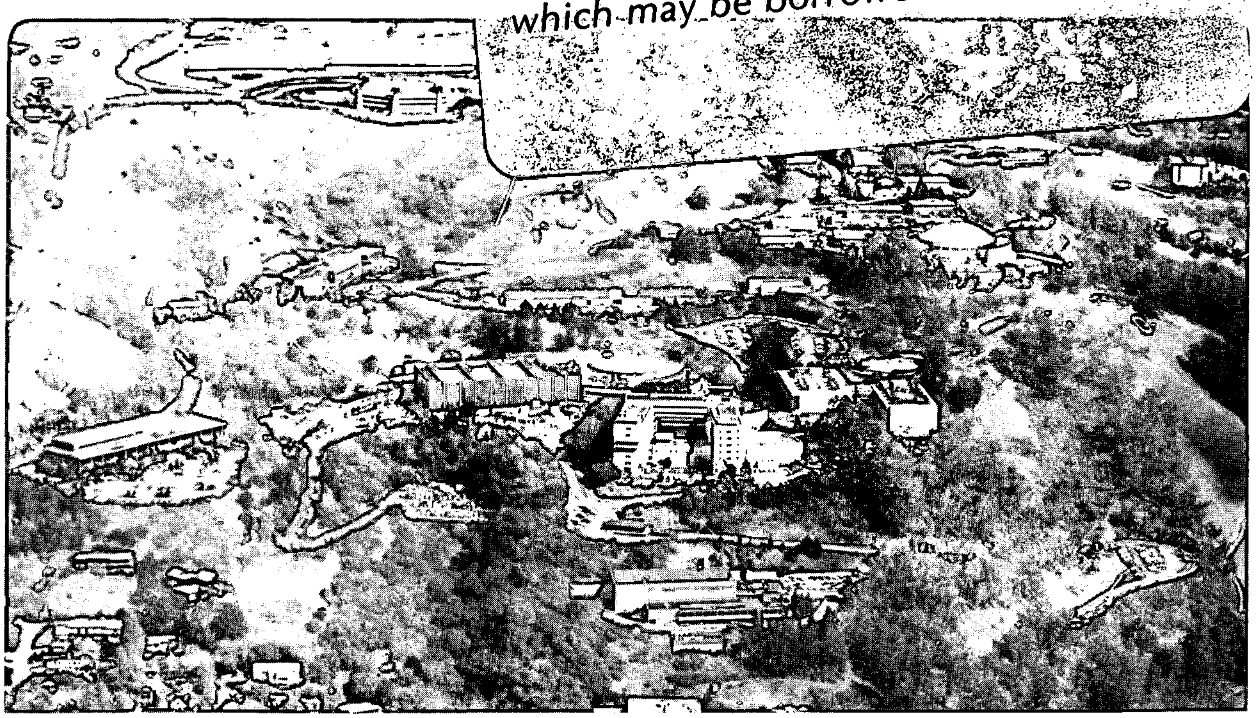

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BEAM POSITION MONITOR SYSTEM FOR STORAGE RINGS*

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Abstract

Beam position monitors (BPM) for synchrotron light storage rings usually consist of beam pickup electrodes, coaxial relays and a narrowband receiver. While accurate, these systems are slow and of limited use in the commissioning of an accelerator. A beam position monitor is described which is intended to be a principal diagnostic during debug and routine running of a storage ring. It is capable of measuring the position of a single bunch on the first or nth orbit to an accuracy of a few percent. Stored beam position is more accurately measured with averaging techniques. Beam position changes can be studied in a bandwidth from DC to a few MHz. The beam monitor electronics consist of a separate amplification, detection, and sampling channel for each beam pickup electrode. Fast switches in each channel permit selection of the nth turn for measurement (single bunch mode). A calibration pulse is injected into each channel after beam measurement to permit gain offsets to be measured and removed from the final data. While initially more costly than the usual beam position monitor system, this system will pay for itself in reduced storage ring debug and trouble shooting time.

Introduction

Accurate measurements of stored beam in synchrotron light storage rings[1] can be made using a multiplexed system by which button electrode signals are processed by a narrowband receiver and selected components. Although some of the components are costly and hand selected, the system cost can be kept low because of multiplexing, but the system is unable to take a snap shot picture of the beam, especially during beam injection. We have proposed a system which is equally as accurate, but also capable of measuring position of the nth orbit of the beam. A prototype BPM system was designed for a proposed 800 MeV electron storage ring which was to function as a dedicated synchrotron light source. The accelerator was to operate with a single 1 ns bunch having an orbit time of 160 ns. At each BPM station four electrostatically coupled beam buttons were to be installed flush-mounted to the beam pipe and arranged orthogonally to the beam axis. A short piece of beam pipe mounted on a test stand from a previous project had pipe dimensions closely resembling the proposed ring, so it was used to check out the prototype BPM system. The beam was simulated with a stationary, terminated antenna, and its position relative to the beam pipe was changed by moving the beam pipe. While the project was not funded the BPM electronics were developed in consideration of future use.

Development and Details of BPM System

The BPM had to be able to measure betatron oscillations on the first or nth turn after injection of a single bunch into the storage ring. This required real time processing of data from all buttons. Once beam was stored the BPM system had to make an accurate measurement of the closed orbit averaging data from many turns. Real time measurement of betatron wavelength at injection requires a separate amplifier chain for the four buttons at each BPM station. A block diagram of such a system is shown in Fig. 1.

For the proposed accelerator the amplifier chains are tuned to the 10th harmonic (62.5 MHz) of the revolution frequency and have a bandwidth of ten percent with a gain of 60 db. Since this frequency is well within normally available bandpass filter and IF amplifier bandwidths, the local oscillator and mixer shown in Fig. 1 are not needed, and the bandpass filter signal is fed directly into an attenuator which in turn feeds the IF amplifier. The attenuator has a range of 40 db. The IF amplifiers drive amplitude detectors which in turn drive fast track-and-hold modules after being amplified by a gain of 10. The track-and-hold is triggered to hold when the pulse has reached its peak.

The prototype BPM system is housed in three NIM modules. A single width module contains the control and calibrate functions, and two double width modules each of which contains two signal channels that process the four button electrode signals. Items such as the bandpass filter, solid state switch, IF amplifier, RF relay, attenuator and track-and-hold module were selected from commercial vendors. For future systems we will design our own devices where it is cost and performance effective.

For the single orbit case the beam bunch signal is coupled to the amplifier inputs via fast solid state switches and bandpass filters that ring at 62.5 MHz. The switches operate in a few nanoseconds and select a particular bunch signal by appropriately counting the nth orbit or turn via the external trigger.

For closed orbit studies of the stored beam the fast solid state switches are continuously closed. The accuracy of our measurements depend on how well we corrected for systematic errors in our calibrations procedure. Scrapers in the beam pipe could be used to determine the exact geometric center of the beam and how it relates to the BPM measurements. The quadrupole magnetic center is determined by bumping its current until beam deflection is no longer detected by the BPM, and the BPM measurements are noted to correspond to the magnetic center of its adjacent quadrupole. This is a technique used at CESR[2].

An integral part of each BPM station is a small computer programmed to read the track-and-hold signals shortly after a measurement is taken. If the signals are out of range, the computer outputs a DAC voltage which adjusts the attenuators. Once acceptable signals have been read by the computer, a calibrator pulse divided by a 4 way splitter is connected to the inputs of the fast switches via RF relays which also disconnect the button signals. The amplitude of the pulses is adjusted with a programmable attenuator until the average of the track-and-hold output signals equals the average of the previously read button signals. The difference between the measured calibration pulses is noted and the beam position data corrected for amplifier gain offsets.

After the single board computers dedicated to

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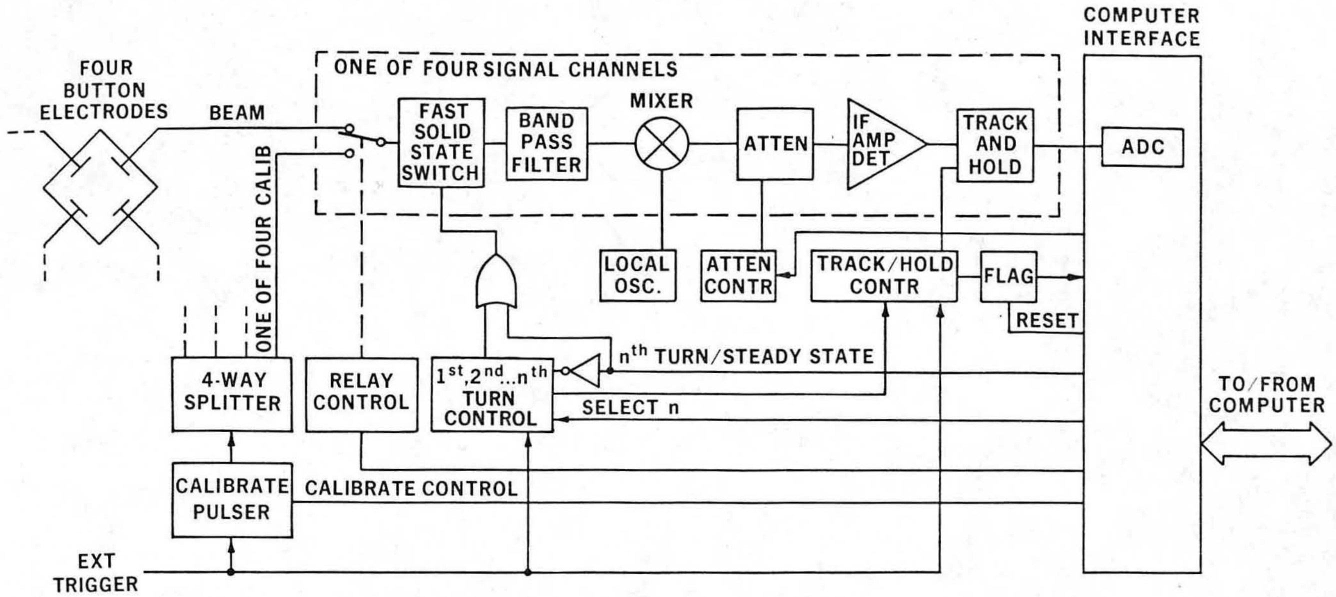

Fig. 1: Block Diagram of BPM System

each BPM station have stored position data, corrections are made for non-linearity of button sensitivity. The data are shipped to a control room display computer via a serial link for appropriate display. By using a scheme of many distributed small computers and a central operator display computer, display of beam position can be made at a 10 Hz rate which is limited primarily by computer processing time. Processed data throughput may also be limited by injection repetition rate or the storage ring rotational frequency and bunch configuration. The BPM signal channels themselves are not a limiting factor on rates in this context.

The test stand holding the short piece of beam pipe is shown in Fig. 2. The beam pipe dimensions are approximately 50 mm x 65 mm. The beam pipe can be moved via the micropositioner stages in the x-y direction relative to the stationary antenna. The plus x-direction is downward and the plus y-direction is to the right in the photograph.

The terminated antenna is shown separately in Fig. 3. The antenna is made of semi-rigid coax cable, and with the distributed resistors terminating the cable, the transverse direction of the electric field is enhanced by the disk placed at the end of the cable. Because the antenna is terminated, the usual problems of shielding and noise pickup are eliminated, and rf and pulse measurements are made with ease.

A personal computer coupled to a commercial data acquisition system was used to control and operate the NIM modules. Programs to control the modules, collect data, adjust gains, normalize data, etc. have been written and checked out for the personal computer.

Results

During closed orbit operation improved accuracy of beam position is made by averaging a number of measurements over many turns where the electronic noise of the system is reduced by the square root of the number of measurements. For example, by taking twenty measurements we can reduce the uncertainty of beam position caused by electronic noise to +/- .01 mm. This is well below the plus or minus +/- 0.1 mm accuracy desired for beam position. The electronic noise comes primarily from the IF amplifier while the dc drift and noise contributions from other components in the system are negligible.

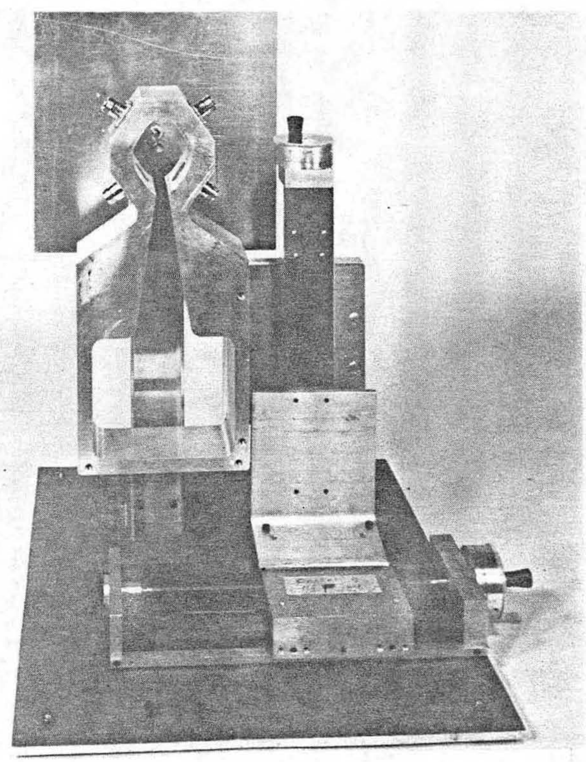

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Fig. 2: Beam Pipe on micropositioner stage

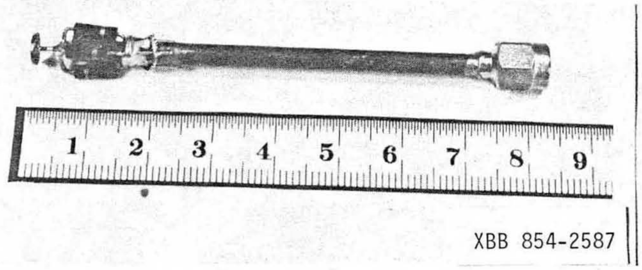

Fig. 3: Terminated antenna

The sensitivity of the button electrodes to beam position in this beam pipe configuration was determined using the technique of others[3,4,5]. Referring to Fig. 2 button A is located at the lower right with buttons B, C and D located counterclockwise, respectively, from button A. The electrical position in the x-direction is given by $S_x \cdot dx = [(A+D)-(B+C)]/(A+B+C+D)$ where A, B, C and D represent the voltages processed for the respective buttons. Likewise, the electrical position in the y-direction is given by $S_y \cdot dy = [(A+B)-(C+D)]/(A+B+C+D)$. The sensitivity curves are shown in Figs. 4 and 5 for x and y, respectively. Also shown on each plot are the curves when the antenna is displaced plus or minus 10 mm in the transverse direction from the motion of the beam pipe. The sensitivity at the center of the beam pipe is 10% per mm for the x-direction and 7.5% per mm for the y-direction. Further corrections must be made to the data to account for the pin cushion distortion due to beam displacement in the pipe and other geometric distortions. A map of the geometric location of the beam with respect to the electrical position is stored in the computer.

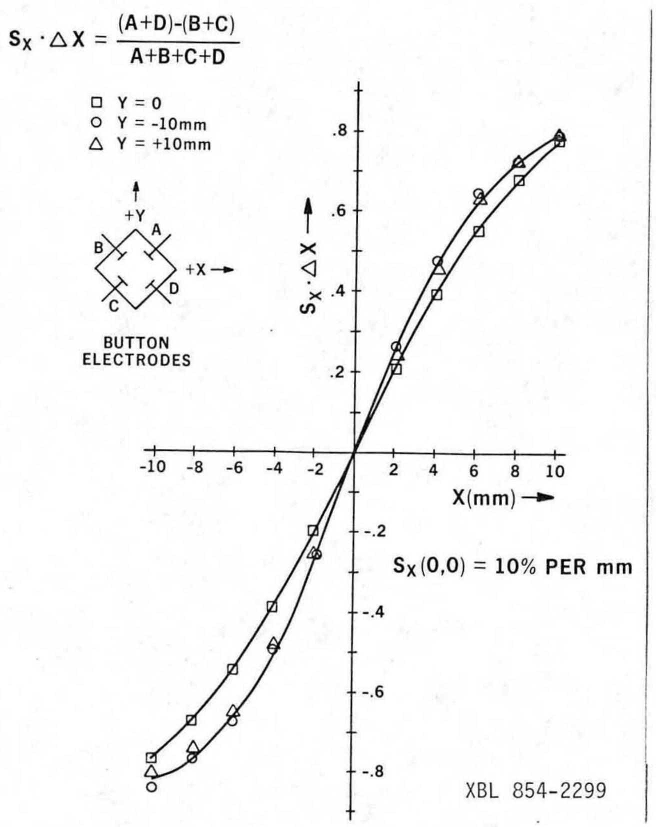

Fig. 4: Sensitivity Curves for x-direction

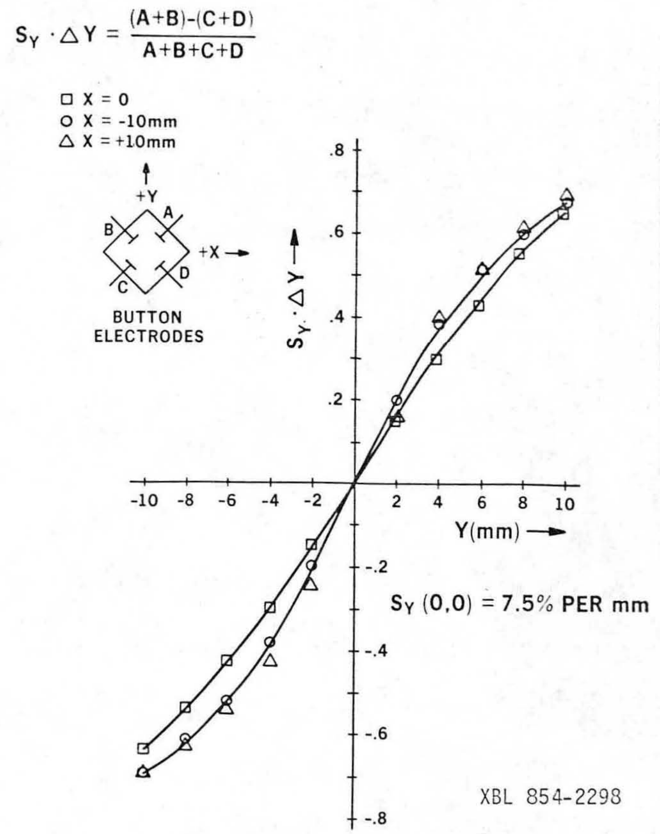

Fig. 5: Sensitivity Curves for y-direction

Conclusion

A beam position monitor system has been designed as a primary tool for the study of beam position instabilities as well as routine closed orbit measurements. Using an input bandpass filter tuned to a beam harmonic and an rf mixer the BPM electronics could be used in many different applications with the single pass feature preserved. Such a system is relatively costly but is justified by the time saved in troubleshooting and tuning an accelerator.

Acknowledgements

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