HIGH PRECISION REAL TIME BEAM POSITION MEASUREMENT SYSTEM *

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Abstract

A system for real time measurement of beam position is being constructed for the ALADDIN electron storage ring. High precision measurements with a bandwidth large enough to allow their use in closed orbit feedback are required. The hardware at each station consists of a pair of position sensing electrodes connected through a PIN diode switch to a narrow band receiver tuned to the second harmonic of the storage ring RF frequency. The receiver input is switched between the electrodes at a 12.5 kHz rate. The output of the receiver is synchronously demodulated to obtain a signal proportional to the difference between the electrode signals. The difference signal is normalized to beam intensity with an automatic gain control (AGC) loop controlling the average output of the receiver. The AGC loop has a useful dynamic range of 80 dB and is capable of reducing beam signal fluctuations at frequencies up to 200 Hz.

Introduction

Precise information about beam position is critical in the operation of electron storage rings used as synchrotron radiation sources. Orbit stabilization methods using feedback require real time position information. Bandwidths of up to several hundred hertz are often needed for this purpose. Real time position data is also useful in locating sources of orbit instability. Resolution requirements placed on position measurements in this application are quite stringent. A useable resolution of 10 μm or less is often required. Short term drifts in the system must be reduced to a minimum. Finally, the system must operate over a wide range of beam intensities and tolerate beam fluctuations without losing its calibration. At the Synchrotron Radiation Center (SRC) of the University of Wisconsin - Madison, a beam position monitor (BPM) system designed to meet these requirements has been developed for use in the ALADDIN storage ring.

System Description

A block diagram of the new system is shown in Fig. 1. The pickup electrodes are pairs of diametrically opposed striplines inside the vacuum chamber[1]. Each pickup is connected through one side of an SPDT PIN diode RF switch to a measuring receiver which is tuned to the second harmonic of the ring RF frequency (101 MHz). The switch is toggled between the pickups at a 12.5 kHz rate, connecting them alternately to the receiver. The demodulated output of the receiver is a 12.5 kHz square wave whose amplitude is proportional to the difference in signal level between the two pickups. The phase of this signal with respect to the switching signal indicates the direction of the position error.

The receiver measures the amplitude and polarity of the difference signal by synchronously demodulating it using the switching signal as a reference. The difference signal must be normalized with respect to signal level in order to have a fixed relationship to beam position. The receiver accomplishes this with an AGC loop acting on the DC component of the receiver output. The AGC loop holds the average receiver output constant, effectively normalizing the difference signal by the average of the two pickup signals. The AGC also cancels any fast fluctuations in signal strength caused by beam instabilities. The position signal is output in analog form after lowpass filtering.

In a full implementation of the system, one receiver and switch are required for each pair of pickup electrodes. The local oscillator signal for all receivers is generated by a crystal oscillator which is amplified and distributed through power splitters to each receiver. The switching reference is obtained by frequency dividing the output of a crystal oscillator and feeding the signal to each receiver and switch in the system. A variable time delay is inserted in the receiver demodulation reference path to compensate for the phase shift in the receiver circuits. The differential delay between receivers can be made small enough to allow a single delay circuit to provide the reference for multiple receivers.

Circuit Details

The RF switch modules are assembled using a commercially manufactured PIN diode switch. The signals from each pickup are passed through an attenuator and wideband (25 MHz) bandpass filter before being fed to the switch. This reduces the 20 volt peak bunch signal to a level of less than 1 volt to avoid overdriving the switch. The attenuator also provides a reasonable termination for the pickup. All of these components along with a switch driver are contained in a small cast aluminum box which is mounted near the pickups. Isolation between the on and off ports of the switch is about 45 dB. This level of isolation is sufficient as long as it remains constant. Any change in coupling between switch ports is detected as a position offset. For this reason, foil shielded coaxial cable is used for all RF connections to minimize stray coupling into the switch inputs.

A diagram of the prototype receiver is shown in Fig. 2. A single conversion superheterodyne circuit with a 455 kHz IF is used. The RF stage is an inexpensive dual-gate GaAs FET designed for use in UHF communications receivers. The input is capacitively coupled to gate 1 of the FET which is terminated in 50 ohms. Capacitive coupling was required to maximize the speed of the PIN switches. The coupling capacitor was chosen as small as possible in order to attenuate the transient signal generated by the operation of the switch. Gain control is applied to gate 2 of the FET resulting in a 50 dB gain control range. Frequency conversion is performed by a diode double balanced mixer.

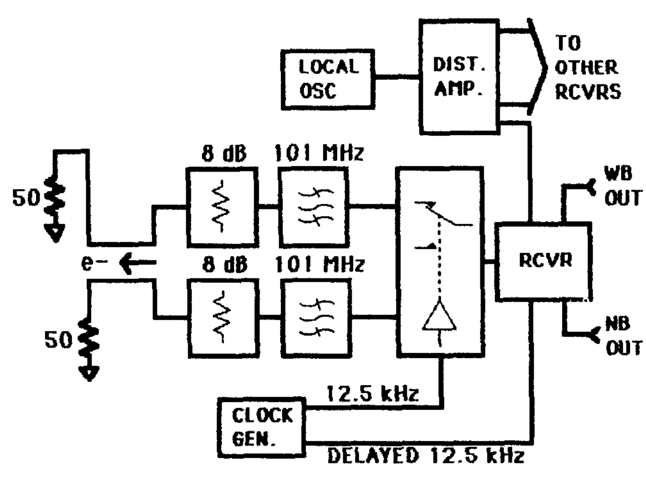

Fig. 1. System block diagram.

* Work supported by the NSF under contract DMR-8601349

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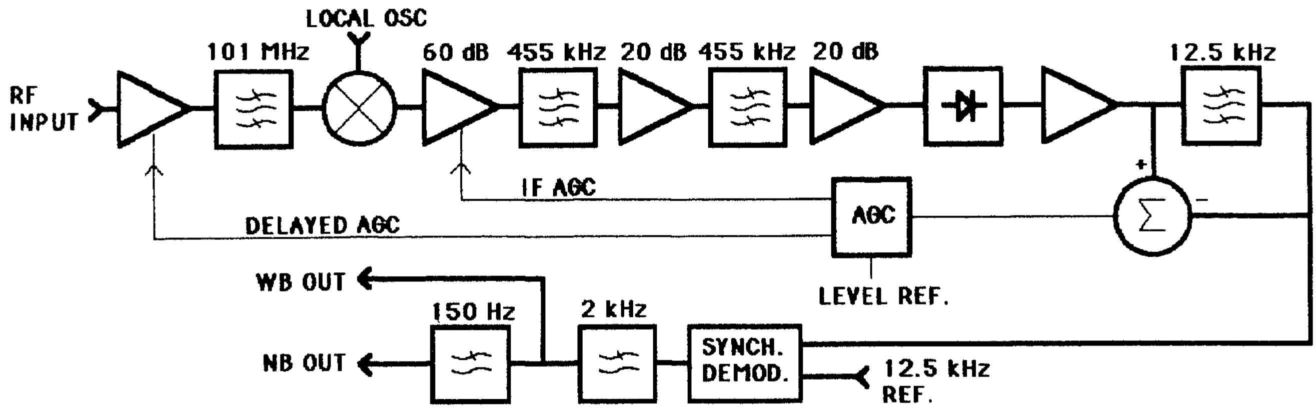

Fig. 2. Receiver block diagram.

The IF gain control stage is a TV IF amplifier IC with about 60 dB of gain and a similar gain control range. A JFET amplifier stage with a gain of 20 dB follows. Two tuned circuits in these stages set the IF bandwidth to about 65 kHz. The final stage is a wideband operational amplifier which drives a Schottky diode detector. The detector diode is biased to improve linearity by adding a DC offset to the amplifier input. After RF filtering, the detector output is fed to a bandpass filter centered at 12.5 kHz with a bandwidth of 4 kHz. This filter is also used in combination with a summing amplifier to form a 12.5 kHz notch filter which is used in the AGC feedback path to eliminate the effect of the switching modulation on the AGC loop.

The AGC amplifier is an operational amplifier integrator which controls the IF and RF amplifiers. Delayed AGC is provided to the RF amplifier in order to optimize signal to noise ratio as a function of input level. The AGC circuit has an adjustable level reference which sets the calibration of the position output. AGC loop bandwidth is wide enough to cancel modulation of the input signal at frequencies below 200 Hz. Loop gain is relatively constant over a 60 dB range. Another 20 dB of range is useable with reduced effectiveness.

The 12.5 kHz normalized difference signal is then synchronously demodulated by a special purpose integrated circuit which switches between gains of +2 and −2 under the control of the reference signal. The output of the demodulator is lowpass filtered in two channels. The wideband (WB) channel has a bandwidth of 2 kHz and is intended for use in feedback systems. The narrowband (NB) channel has a bandwidth of 150 Hz and is connected to a computer in the control system for position measurement. Full scale range for both is ±5 volts.

Design Considerations

The choice of a switching frequency (f_{sw}) requires some consideration of possible spurious responses. Any modulation on the beam signal which is near the frequency of a spurious response will give a false position indication. This implies that synchrotron and betatron sidebands must not occur near $f_{RF} \pm f_{sw}$. If the image frequency cannot be filtered out, these considerations apply to it also. Clearly, f_{sw} must be high enough to allow the bandwidth required of the position measurement to be obtained without difficulty. The upper limit on f_{sw} is usually determined by the high frequency limitations of the demodulator and filter circuits. The choice of 12.5 kHz was made in our case because this frequency is bracketed by the first and second synchrotron sidebands. Choosing a higher frequency would have resulted in a narrower spurious free window.

An unanticipated problem was discovered in testing the prototype receiver. A number of spurious responses resulting from intermodulation between the IF frequency and higher order harmonics of f_{sw} were detected. They are normally suppressed by about 50 dB but increase in level at larger position errors as the modulation of the IF signal at f_{sw} increases. Examining the IF waveform showed that these products are produced in the detection process. They are evidenced by a change in the shape of the difference signal waveform at its edges as the relative phase of the IF carrier and f_{sw} modulation varies. It should be possible to reduce these responses to insignificant levels by choosing a higher value for f_{IF}/f_{sw}. Another prototype receiver using a 10.7 MHz IF is being constructed for further testing. The new receiver will utilize an integrated gain controlled IF amplifier and quasi-synchronous detector circuit which will substantially reduce the number of components in the receiver.

Performance

An plot of the NB output is shown in Fig. 3. The data was taken at the ring injection energy of 108 MeV and shows 60 Hz motion due to an AC component on the ring correction dipole magnets. The amplitude of the signal represents motion at the pickup of 100 μm peak. A measurement system of this type is potentially quite useful for locating the sources of similar disturbances which are transient or too high in frequency for a simple BPM system to detect.

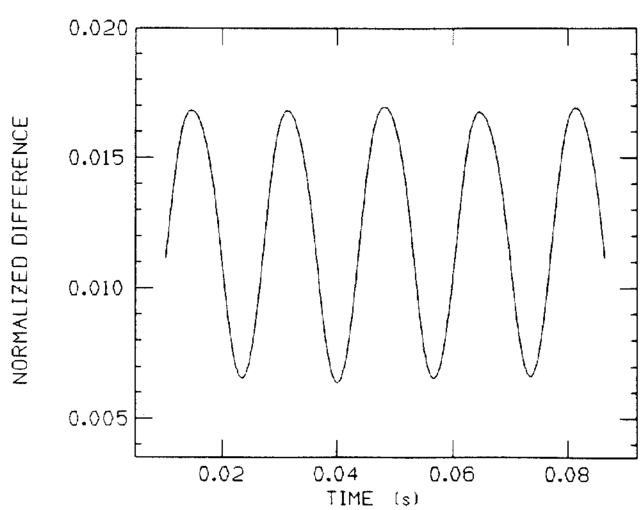

Fig. 3. Signal from receiver NB output showing 100 μm peak motion at 60 Hz.

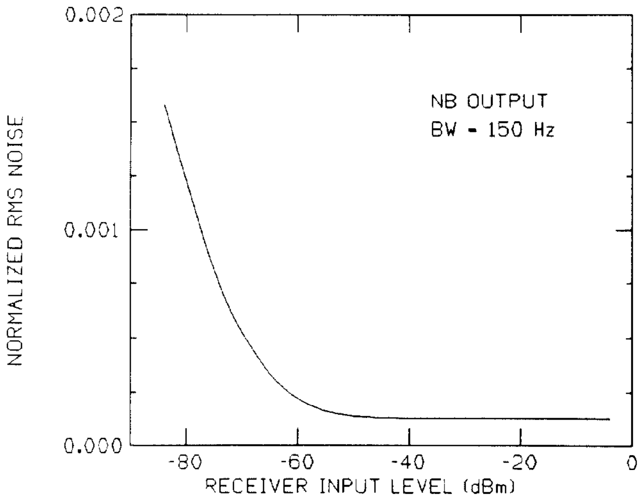

Fig. 4. Noise level of NB output vs. input RF level.

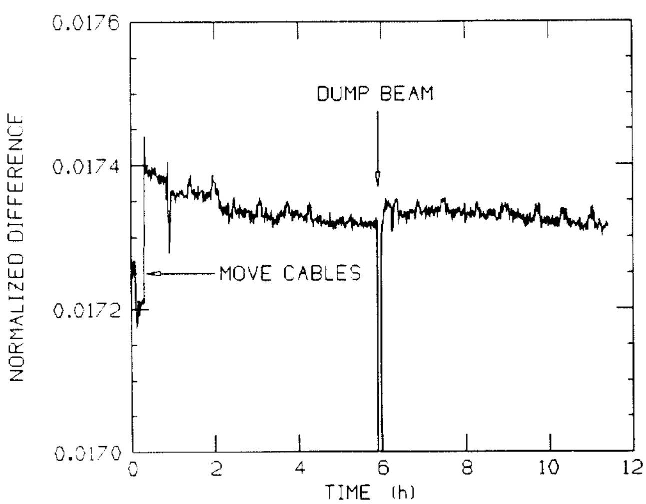

Fig. 5. Mean value of NB output vs. time with both switch inputs connected to the same electrode.

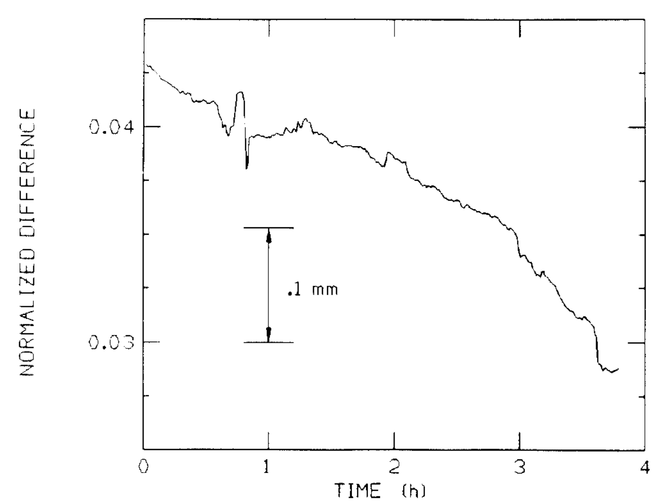

Fig. 6. Position at horizontal BPM station taken during 2 mA alignment beam.

Fig. 4 is a plot of the noise level of the NB output as a function of RF power at the receiver input. The noise is relatively constant over a 60 dB range which is more than adequate for normal operation. The remaining 20 dB of range is useable with reduced resolution which allows operation at very low beam currents.

Stability over periods of hours is excellent after a short warmup period. Fig. 5 is a plot of the average value of the NB output over the course of several hours. The data includes two fills of the ring and subsequent decays of the beam. The inputs to the switch were derived from only one pickup electrode during this measurement to eliminate any position information. Very little intensity dependence or drift is evident in the data. Most of the observed variation is attributable to differences in stray pickup resulting from changing the position of the electrode cables. Careful construction of these cables is essential to avoid inconsistant measurements.

Fig. 6 is an actual position history recorded in the same manner as Fig. 5. This record shows the position at a horizontal BPM station during a 2 mA alignment beam in ALADDIN at the normal operating energy of 800 MeV. A linear drift and a few position jumps are evident, the source of which is unknown. Occasionally, drifts are observed for a short period after ramping. These drifts are attributed to small changes in the ring magnets as they stabilize after the end of the ramp.

Conclusion

The real time measurement of beam position with high accuracy is a requirement in the operation of modern synchrotron radiation sources. The system described here is relatively inexpensive and has proven itself to be a practical means of obtaining accurate real time position data. A partial implementation of the system using a small number of receivers will begin at SRC in the near future. Full implementation of the system is anticipated when time and funding permits.

References

1. K. J. Kleman, Proceedings 5th Natl. Conf. on Synchrotron Radiation Instr., Nucl. Instr. and Meth. **A266**, 172 (1988).