PERFORMANCE OF THE UPGRADED NSLS BEAM POSITION MONITORS

R.J. Nawrocky and J. Keane
National Synchrotron Light Source, Brookhaven National Laboratory, Upton, NY 11973

Abstract

The design and initial performance of the original NSLS beam position monitor (BPM, also referred to as the "rf receiver") were described by J. Bittner and R. Biscardi in 1989 [1]. The receiver, which processes signals from four button type pick-up electrodes by time-division multiplexing, operates at the third harmonic of the ring rf frequency (158.66 MHz). It has an output bandwidth of about 2 kHz and a dynamic signal range of approximately 36 dB. A total of 92 receivers have been installed in the NSLS X-ray and VUV storage rings for orbit monitoring and for real time feedback.

As part of a continuous effort to improve the NSLS storage ring performance, the BPMs as well as other instrumentation systems have also been undergoing upgrades over the past two years to improve their performance. In the BPM, the front end has been modified to prevent saturation of the rf multiplexing switch, the detector operating point was changed to improve output signal linearity, the dynamic range was increased to over 60 dB, and the gain calibration was standardized to 0.5 volts/mm (i.e. 2 μm/mV). This paper describes the BPM modifications and presents some performance data and measurements on stored beam.

1 INTRODUCTION

The NSLS storage rings operate with many different fill patterns – from one to nine bunches in the VUV ring (normal operation is with seven bunches), and from one to thirty bunches in the X-Ray ring (normal operation is with 25 bunches). The harmonic numbers of the VUV and X-ray rings are 9 and 30, respectively. Initially, the X-Ray ring stored current in the multi-bunch mode was limited to 250 mA due to heating of the beam-line front ends and in the single bunch mode it was limited to 100 mA due to heating of the inflector chamber.

In the VUV ring, on the other hand, the maximum stored current in multi-bunch mode could be as high as 1000 mA while single bunch intensity was limited to 400 mA. The Bittner-Biscardi receivers, which were intended for use in both storage rings, had sufficient sensitivity to measure beam position at an intensity level of 0.16 mA/bunch (i.e. 4 mA in 25 bunches) but had a dynamic range of only 36 dB. Accordingly, the range of the X-Ray ring receivers was set to 4-250 mA, while that of the VUV ring receivers was set to 16-1000 mA. At high beam intensities (near 100 mA/bunch), however, the PUE peak signal levels were approaching the saturation level of the front end rf switch, even with the 300 MHz input low pass filters ahead of the switch. In addition to saturation of the multiplexing switch and limited range of the AGC, a disadvantage of the original design was the fact that the setting of the detector operating point was directly affecting the gain calibration of the output channels and that the gains of the two output channels could not be set independently. Thus, each receiver had somewhat different gain coefficients which complicated record keeping as well as troubleshooting. Once the front-end heating problems in the X-Ray ring are solved, the stored multi-bunch beam intensity will be increased to the design value of 500 mA. The single bunch limit has already been increased to over 200 mA. Since the X-Ray ring active interlock system is routinely tested at about 6 mA (any bunch pattern), the receivers must now operate over an intensity range from labout 0.16 mA/bunch to greater than 100 mA/bunch, i.e. over a range of about 60 dB.

The original NSLS BPM design proved to be quite reliable and the receivers performed well over a period of nearly seven years. With ninety-two BPMs installed and in continuous operation, the failure rate has been less than one per month. Improvements in machine operation, i.e. a wider range of stored beam current and demand for higher intensity single bunch runs, called for the enhancement of BPM capability which resulted in the design upgrade effort described in this report. Presently, all of the 48 X-ray ring orbit BPMs have been upgraded and work on the X-ray ring active interlock system BPMs and VUV ring orbit BPMs is underway.

2 BPM UPGRADE

A block diagram of the upgraded BPM is shown in Fig.1. As mentioned earlier, the following changes were made to the original design:

0-7803-4376-X/98/$10.00 © 1998 IEEE

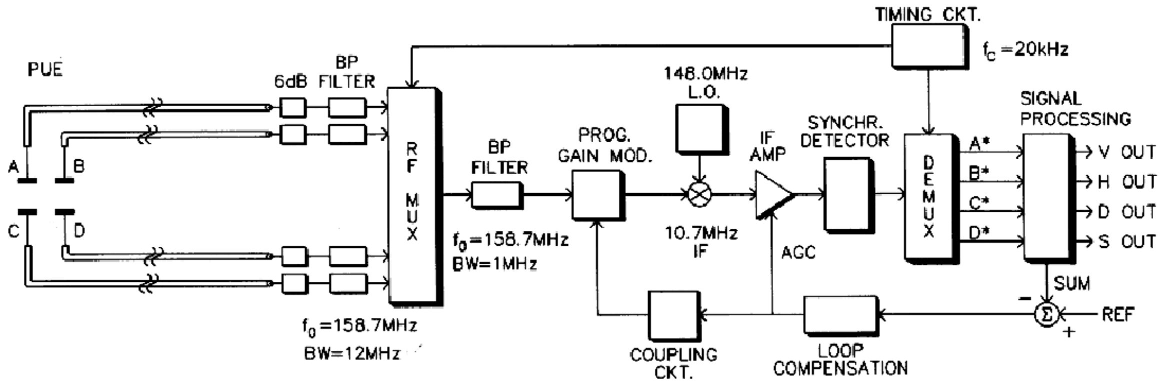

Fig.1. Block diagram of the upgraded BPM

Front End – In the original design, the PUE signal pulses were first processed by a 300 MHz low-pass filter (to limit peak amplitude) and then applied to the GaAs 4PST rf multiplexing switch. In single bunch high current mode, the peak signal voltages were approaching the saturation level of the switch. Attenuating the PUE signals with broadband attenuators would avoid switch saturation, however, it would also reduce the BPM sensitivity by attenuating the 158.66 MHz component processed by the receiver.

This problem was solved by adding a low-cost 12 MHz band-pass (BP) filter to each BPM input. These filters are used in addition to the costly and bulky 1 MHz band-pass tuned cavity filter which is needed to reject the revolution harmonics. A 6 dB attenuator pad was added ahead of each filter to help damp out reflections of the out-of-band components at the filter end as well as any re-reflection at the “open” PUE button electrode end.

Dynamic Range – To increase the dynamic range of the BPM, a wideband programmable gain stage (PGM) was added ahead of the IF mixer (see Fig. 1). This stage consists of a voltage controlled attenuator module (Watkins-Johnson, G-2, 3-31 dB range) followed by a 22 dB low noise amplifier (WJ-A81-2). The addition of the amplifier in the PGM resulted in an increase in the level of the rf switch noise at the input to the IF mixer at low input signal levels. This problem was solved by decreasing the clock frequency from 40 kHz to 20 kHz and delaying the 4 μs de-multiplexing pulse to the end of the overall 12.5 μs PUE button sampling period. The 20 kHz clock frequency is just over a factor of two higher than the VUV ring synchrotron oscillation frequency (VUV ν_s = 9 kHz, X-ray ν_s = 4 kHz).

Detector Operating Point – The output dc operating point of the video detector (Motorola MC1330) was moved down to 5.0 volts to improve the linearity of the BPM output signals over the full ±10 mm range of beam displacements.

Gain Calibration – Gain potentiometers were added to the signal processing board to permit the setting of the vertical and horizontal gains independently of each other and of the detector operating point.

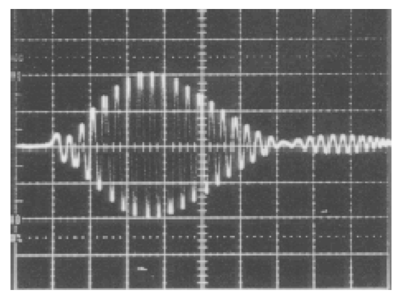

Fig. 2. Response of the 12 MHz BP filter to a 6V, 2ns-wide input pulse (10 mV/div, 10 ns/div).

3 PERFORMANCE OF THE UPGRADED BPM

Referring to Fig.1, the 12 MHz input BP filters reduce the peak signal amplitude by approximately 50 dB. This is illustrated in fig. 2 which shows the filter response to a 6V peak, 2 ns-wide input pulse.

The minimum detectable signal (MDS) was measured in the laboratory for the original and the upgraded receivers using an amplitude-modulated rf signal source and a four-way hybrid splitter. In each case, a 158.66 MHz rf signal modulated with a 1 kHz sinewave was applied to the input and the detected signal approximately 6 dB above the “noise floor” was observed at the BPM sum signal output. The measured data for the two cases is given in Table 1.

Table I.

BPM Configuration	RF Input (dBm)	Noise Floor (dBVrms)
Original	-80	-65
Upgraded	-100	- 62

The above data shows that, as expected, the PGM improves the MDS by 20 dB while increasing the noise floor only by about 3 dB. Figure 3 shows the error in the overall response for centered as well as off-center beams. Fig.3 data was generated using an rf signal source, a four-way splitter and fixed attenuators and does not include nonlinearities due to electric field distribution within the actual PUE assembly. Thus, the output error of the upgraded receiver is under ± 10 μm for beam displacements up to ± 10 mm over a dynamic range greater than 60 dB.

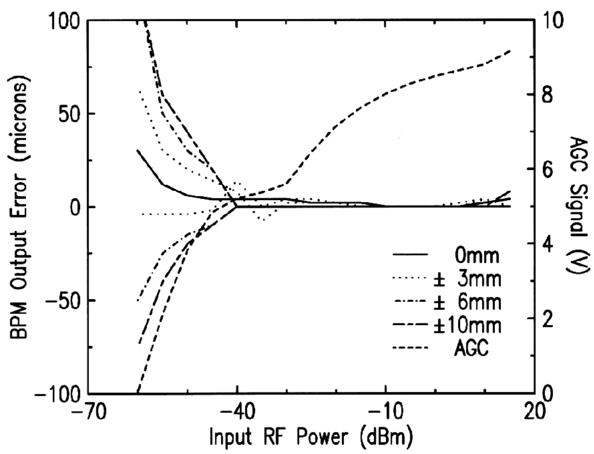

Fig. 3. Error in BPM output signal as a function of input rf power for simulated beam displacements up to ± 10 mm.

The noise level in the BPM output corrupting the beam position signal varies inversely with the input signal strength, while its bandwidth is limited to 2 kHz by low-pass output filters, as shown in the spectrumm of the noise in fig. 4. Note that the -60 dBV level corresponds to 1 mV rms which is equivalent to 2 μm rms of beam motion. As an illustration of BPM operation with stored beam, fig.5 shows the vertical beam position output signal and the AGC voltage of one of the ring monitors during a typical injection cycle into the X-ray ring. Data in figures 4 and 5 can be related in terms of the AGC signal, i.e. the two figures permit a translation from rf signal power in dBm to stored beam current in mA and vice versa. The small variations in beam position signal during injection (Figure 5) indicate normal beam motion when orbit feedback is switched off. During stored beam operation, closed orbit feedback reduces the motion to a few microns.

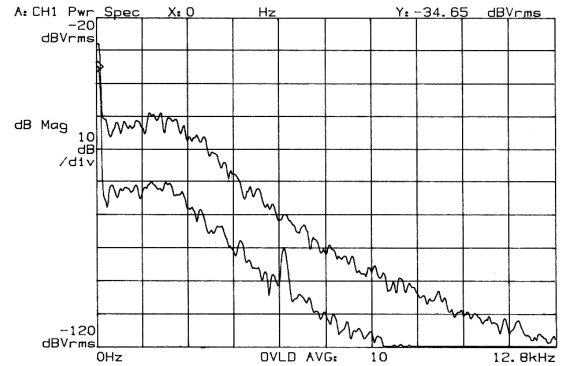

Fig. 4. BPM output noise spectrum with no input signal (upper trace) and with input power = 0 dBm (lower trace).

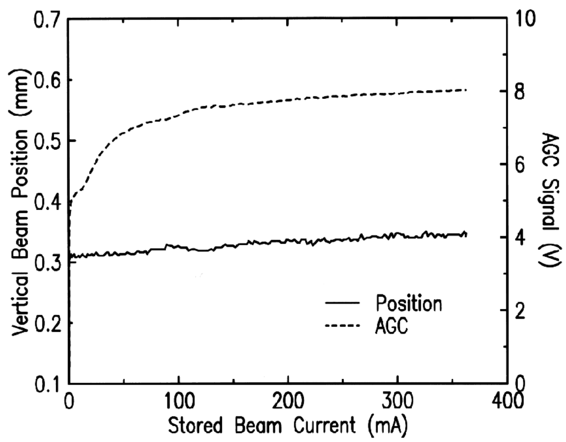

Fig. 5. BPM vertical output signal and AGC voltage during injection into the X-ray storage ring.

ACKNOWLEDGEMENTS

The following individuals contributed to the design and implementation of the BPM upgrade as described: M. Bordoley, A. Borelli, J. Tallent and O. Singh. This work was performed under the auspices of the U.S. Department of Energy under contract number DE-AC02-76CH00016.

REFERENCES

[1] R. Biscardi and J. Bittner, “Switched Detector for Beam Position Monitor”, Proc. Of 1989 IEEE PAC, pg. 1516.