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Test Results of the SSC Log-Ratio Beam Position Monitor Electronics

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Abstract

A working prototype of Beam Position Monitor (BPM) electronics, based on the log-ratio technique is described in this paper. Results of a test performed at the Fermilab Booster, comparing the existing Fermilab BPM system are also presented. A calibration technique has been used which corrects errors due to mismatched channels and electronics drift. The results are compared with bench measurements on the prototype circuit.

I. INTRODUCTION

The log-ratio technique for BPM electronics has recently been investigated at many laboratories and encouraging results have been obtained from bench testing. A test was performed at the Fermilab Booster in order to understand the performance limitations in the field. The machine the log-ratio electronics was tested on presents some interesting problems. The RF frequency is ramped from 30MHz to 53MHz in 33ms, and the average beam current increases during the acceleration cycle changing the signal amplitude presented at the input of the electronics. A test on this machine has a direct interest for the SSC because of the similar parameters of the Low Energy Booster. A direct comparison of the log-ratio BPM electronics, built at the SSC, with the Fermilab Booster AM/PM electronics is described in this paper. The signal from the BPM electrodes was split in order to provide a simultaneous source to both systems. The outputs were digitized by the same ADC module and later processed.

II. LABORATORY RESULTS

A. Position Characteristics

The log-ratio technique for BPM electronics is based on equation 1, [1], where S_x is the sensitivity in dB/mm, \mathcal{V}_A and \mathcal{V}_B the signal amplitudes at the output of the BPM electrodes.

$$x = \frac{1}{S_x} \times \left(20 \times \log \frac{\nu_A}{\nu_B} \right)$$
(1)

Bench performance is extensively described in previous publications [2], [3], [4]. The two plots which best summarize the performance are shown in figures 1 and 2.

Circuit linearity is an important consideration in measuring position over the complete range of beam current and to accurately measure displacement from center. The logamp electronics have demonstrated a linearity of 1% error over an input power dynamic range of 70dB. A plot of simulated position vs. beam current was obtained by applying a source signal from a signal generator to both channels of the log-ratio electronics. Ramping the power level of the generator over the electronics dynamic range simulated a changing beam current. A simulation of beam displacement off center was accomplished by changing the power ratio of the two signals while again ramping the input power. The circuits dynamic range over a simulated beam displacement of ± 10 mm is demonstrated in figure 1. A sensitivity of 1dB/mm, which corresponds to a circular beam pipe of radius 33mm, was chosen for graph legibility.



Figure 1. Simulated beam fluctuation.

B. Noise Characteristics

The resolution of the position measurement is limited by the signal to noise ratio, according to the following expression [1]:

$$\delta_{x} = \frac{b}{4} 10^{\left(\frac{P_{N} - P_{s}}{20}\right)}$$
(2)

where b is the beam pipe radius, P_N is the noise power and P_S is the signal power, both in dBm. The theoretical noise power is expressed by [5]:

$$P_N = 10\log(\frac{KTB}{0.001}) + NF$$
 (3)

where K $[J/K^{\circ}]$ is Boltzman's constant, T $[K^{\circ}]$ is temperature, B [Hz] the bandwidth and NF [dB] is the noise figure. The noise figure is derived by measuring the position resolution at a given signal power, and calculating the noise power at the measured conditions. The theoretical curve derived by equations 2 and 3, using NF=0, and the experimental curve of the logamp response is shown in figure 2. The noise figure is derived by

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measuring the distance in the horizontal axis between the two curves, which is 15dB.



Figure 2. Beam position resolution as a function of input signal amplitude.

III. FERMILAB TEST RESULTS

Position measurements of the Fermilab Booster were taken with the test setup shown in figure 3. Signals A and B originated at a set of horizontal beam pickups. During normal operation, these signals would be terminated in Fermilab's RF module which incorporates the AM/PM method of beam detection [6]. The signals were split and sent to both the RF module and the log-ratio circuit. The outputs of both circuits were digitized by the same ADC module running at a sample frequency synchronized to the revolution frequency. The injection synchronization pulse arrives at the beginning of the Booster cycle and arms the ADC. The Trigger Generator produces a pulse



Figure 3. Block diagram of the log-ratio, AM/PM position test conducted at Fermilab.

which tracks the frequency sweep of the Booster with the low level RF. This signal triggers the Pulse Generator, which provides a signal for the ADC module, and triggers the digitizer on every fifth revolution, the quickest rate available. A plot of the beam position vs. the number of turns, using the log-ratio circuit, is shown in figure 4. A corresponding plot of the beam position obtained with the RF module was used for comparison. The difference between the log-ratio circuit and the RF module positions is shown in figure 5.



Figure 4. Measured position vs. number of turns through one acceleration cycle with the log-ratio circuit.

After the first 4000 turns, the results are as good as can be expected, considering the errors associated with the two systems. The typical offset for the Booster RF module is approximately 0.5mm. The error of the log-ratio circuit, due to ripple caused by saturating gain stages internal to the logamp, could be as high as ± 0.1 mm, with the Booster sensitivity of 0.52dB/mm. 12 bit ADC's are used in the digitizer. With a half bit of noise, $\pm 16\mu$ m could be realized with the log-ratio electronics and $\pm 165\mu$ m with the RF module. The position signal from the RF module was provided from its 20dB attenuation port, which would account for the greater displacement. These ADC resolutions causes the ripples seen in figure 5, not the general shape of the curve.

During the first 4000 turns several other factors must be considered in understanding the plot of figure 5.





The beam signal intensity increases by about 10dB and the revolution frequency sweeps from 30MHz to 47MHz in this early part of the cycle. The frequency as a function of the number of turns is shown in figure 6.

The contributions to the error plot of the log-ratio electronics is due to both amplitude and frequency. The electronics is certainly processing the beam signal through its maximum range of linear response error, which appear as the ripples in figure 1, and corresponds to ± 0.1 mm. The amount of position deviation as a function of frequency expected is on the order of 0.08mm. Both these numbers were verified by bench testing at the SSC.



Figure 6. RF frequency vs. number of turns at the Fermilab Booster.

Errors due to the AM/PM electronics are a little harder to discuss because an RF module was not available for lab testing. However, there are a few factors which could account for at least part of the total error. During the early period of acceleration, the beam displacement is in the range of 7mm to 13mm off center. Considering the Booster sensitivity, this is in the range where the AM/PM response is becoming nonlinear. Although a correction formula was used to calculate position, there is still some amount of error associated with this nonlinearity. Important also is the error due to the frequency sweep. Down converters and limiters both contribute to the total error which could be as large as ±0.4mm [7].

The contribution of all the errors amounts to about 1 mm, which is not out of line with the plot of figure 5.

IV. CONCLUSIONS

The log-ratio design will be utilized in the SSC's Linac. This design will be implemented in conjunction with a frequency down-converter from 428MHz to 60MHz. The IF frequency was chosen with the intention of consolidating a design which may also be suitable for the other SSC machines.

Through incorporating relatively minor design changes, this log-ratio circuit will also be proposed for service in the SSC's Low Energy Booster (LEB). With the LEB sensitivity slightly greater than that of Fermilab's Booster, 0.72dB/mm as opposed to 0.52dB/mm, and a narrower frequency sweep from 47MHz to 59MHz, instead of 33MHz to 53MHz, frequency compensations won't be necessary. The experience at the Fermilab Booster has taught us to be careful here. It is critical that the input filters be well matched through this frequency sweep. An impedance mismatch as a function of frequency will result in a direct position error.

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