PERFORMANCE VERIFICATION OF THE DIAMOND EBPM ELECTRONICS

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Abstract

The Electron Beam Position Monitor electronics for Diamond are a newly developed product. As such, extensive testing was carried out as part of the acceptance tests. These tests included measurement of the resolution, beam current dependence, fill pattern dependence, temperature dependence and long term reproducibility in the lab. A setup of signal generators was chosen to simulate the signals from button pickups as realistically as possible. Additionally, tests have been carried out with "real beam" signals at the SRS in Daresbury. Solutions for problems identified during these tests have been developed and their suitability is demonstrated.

INTRODUCTION

Diamond will incorporate 202 *Libera* beam position processors from Instrumentation Technologies for use in the transfer lines, booster and storage ring. The specifications required the resolution to be measured for a range of beam currents and for different acquisition bandwidths and data rates to cater for fast feedback (FFB) and turn-by-turn (TBT) applications (see table 1). Additionally, any systematic offset of the beam position reading correlated with the beam current had to be recorded and within the given limits.

The resolution and beam current dependency test are carried out as part of the factory acceptance test. They were repeated for a sample of the delivered units and additional long term tests were conducted.

LAB TEST SETUP

To facilitate parallel tests of 6 sets of BPM electronics in the lab they were put in one rack and connected to an RF signal generator (Rohde & Schwarz SML01, $f_{RF} = 499.654$ MHz) through a network of power splitters. Additionally, an arbitrary waveform generator (Agilent 33250A) simulated the 2/3 fill of the storage ring by producing a $f_{rev} = 533818$ Hz with 66% duty cycle and delivering this to the fast gate input of the RF generator. This signal was also sent to a custom built trigger fan-out unit, which provided it as machine clock to the BPM units. To phase lock RF and machine clock as well as to ensure frequency stability during long term tests, both generators had their 10 MHz reference inputs connected to a Stanford FS725 rubidium standard. BPMs and the RF generator were connected to Ethernet so that all tests could run completely remote controlled.

Table 1: Specified r.m.s noise and beam current dependence on position readings for different sample rates and beam current ranges

beam current	resolution@bandwidth 2 kHz	266 kHz	beam current dependence
60-300 mA	0.3 μm	3 μm	1 μm
10-60 mA	0.6 μm	6 μm	50 μm
1-10 mA	1.5 μm	15 μm	100 μm

DEGRADED RESOLUTION DUE TO HARMONIC FOLD BACK

During the initial resolution tests a strange phenomenon was noted. As long as the sampling frequency of the ADCs is free running, the results are as expected. However, as soon as the machine clock is supplied and the frequency locked loop (FLL) sets the sampling frequency $f_S = 220 f_{rev} = 220/936 \cdot f_{RF}$, the noise on the position readings increases by a factor of 3-5.

An understanding of this phenomenon requires a look at the processing chain (see figure 1). The source for this behaviour is some nonlinearity in the ADCs. This nonlinearity creates the third harmonic of the input signal. In the digital domain, the signal is at $56 f_S$, so the third harmonic will be folded back to $(220 - 56 \cdot 3) \cdot f_S = 52 f_S$. Here, the third harmonic would still be filtered out by the decimation filters in the digital down converter (DDC). However, with the fill pattern square wave modulation at f_{rev}, the signal as well as its third harmonic, carried sidelines at $\pm n \cdot f_{rev}$. The forth sideline of the third harmonic will then come to lie at $56 f_S$, which is the signal frequency. As the FLL locks the VCXO within about 1 Hz, the third harmonic signal will move around and depending on the individual nonlinearities of the four ADCs, create a position fluctuation.

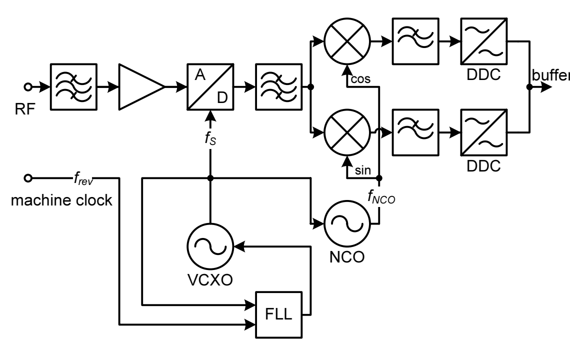

Figure 1: Simplified processing chain for one channel

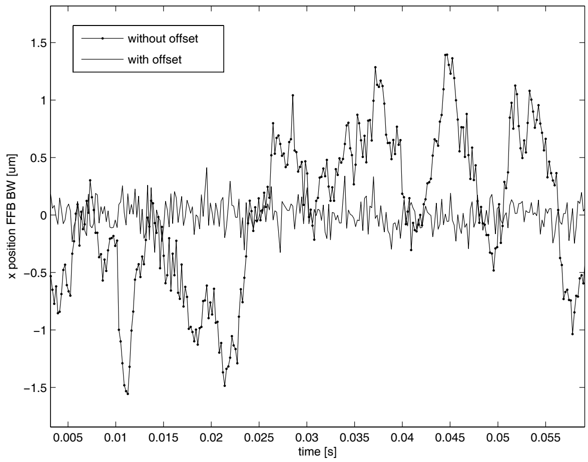

Figure 2: Reduction of position noise by applying an offset to the sampling frequency

The solution to the problem is to offset the VCXO slightly, that is to make $f_S = 220 f_{rev} + f_{offset}$. A few kHz offset are enough to move the detrimental effect of the third harmonic outside the FFB bandwidth. This offset will translate to the signal frequency in the digital domain and is then be corrected by also offsetting the NCO by the same amount. By doing this, the filters in the DDC need not be adjusted. Figure 2 shows a position reading without this offset and after applying the VCXO and NCO offsets.

RESOLUTION MEASUREMENTS

In the lab, the variation of beam current is simulated by changing the power of the RF generator accordingly, taking losses in the power splitter network into account. It has been calculated from the pickup geometry and the cable losses that a continuous (that is un-gapped) stored current of 300 mA would provide a power of -8 dBm to the input of the BPM. However, the peak current at 2/3 fill is 450 mA so the RF generator needs to provide -4.5 dBm

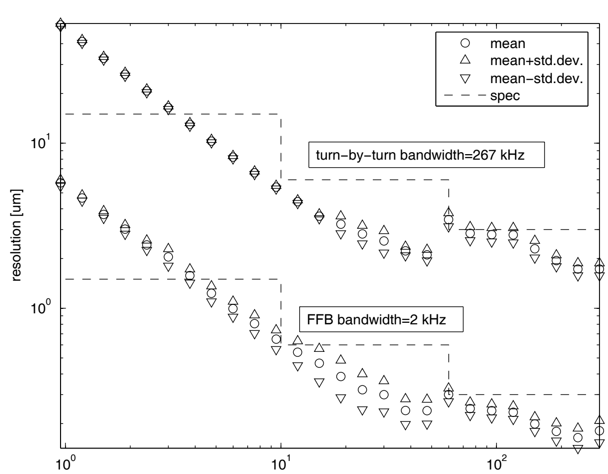

Figure 3: Statistics of resolutions from 48 units

peak power to each input of the BPM electronics. All data reproduced in this report has been measured with 2/3 fill and this conversion can thus be applied at all times.

Figure 3 shows the statistics of 48 units measured at DLS. It can be seen that the resolution specifications were met for both bandwidths and for all currents above 4 mA. At this level, thermal noise is the dominant noise source and the "attenuator reserve" has been used up. As a result the product of beam current and resolution is constant. However, no operational implications for Diamond are foreseen due to this, as the FFB is not intended to be operated at such low beam currents.

BEAM CURRENT DEPENDENCE MEASUREMENT

The position reading of a BPMs should ideally be independent of the beam current. With parallel processing channels, unequal nonlinear response or unequal attenuator steps of the individual channels lead to a position offset as a function of beam current. The crossbar multiplexing of *Libera* should eliminate this effect [1].

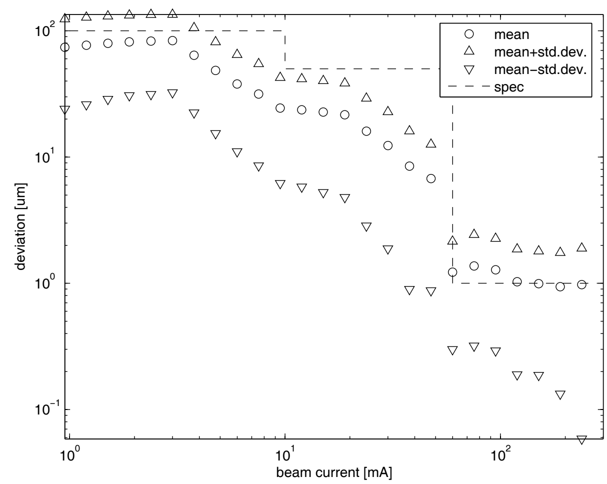

Figure 4: Statistics of beam current dependence from 48 units

Figure 4 shows that on average the goal of a maximum of 1 μm position offset for beam currents between 300 mA and 60 mA has been met. However, that also means that half of the tested units actually showed a higher beam current dependence (up to 2-3 μm). This deviation should be reduced through ongoing efforts to incorporate signal conditioning in the digital signal chain, which will implement linearisation, cross talk compensation and channel to channel phase equalisation.

TEMPERATURE DEPENDENCE

The temperature dependence of the position reading has been investigated by measuring it at different power levels and slowly changing the environmental temperature of the BPM electronics. Temperature coefficients have

Table 2: Statistics of temperature dependence coefficients [μm / °C] for 6 units

	100 mA		10 mA		1 mA	
Unit	x	y	x	y	x	y
5	0.10	0.07	1.7	0.7	3.9	2.8
8	0.12	0.20	1.7	2.4	3.3	7.7
12	0.19	0.01	2.9	2.3	7.7	7.3
14	0.16	0.06	2.4	2.0	5.8	6.3
16	0.13	0.05	4.1	2.1	12	5.5
20	0.15	0.13	2.4	1.8	5.5	5.0
μ	0.114		2.21		6.07	
σ	0.058		0.81		2.47	

been retrieved using linear regression. Table 2 shows a systematic trend of increased temperature dependency at lower simulated beam currents.

LONG TERM STABILITY TEST

The test rack was installed in a temperature controlled environment (±1°C). A script controlled the RF generator to set different power levels and retrieved the position data from all 6 BPM units. This setup was left to run for 30 days. After some initial dropout due to problems with the BPM internal software and the temperature control of the room, a continuous 21 day run has been achieved. Overall, virtually no drift of the position reading could be observed during this long term test (see figure 5).

“REAL BEAM” TESTS AT THE SRS

One *Libera* has been installed at the SRS in Daresbury. It has been running continuously for 50 days now. Two ways of collecting data are available at the moment: on the one hand, a script can be executed to store the current position readings in a file at an interval (some seconds). On the other hand, an EPICS driver can be started so that data can be read directly using Channel Access, for instance into Matlab.

Using the first method, the beam current decay and beam motion during a day has been visualised in figure 6. The second method has been used to capture the kick of the beam during injection (the pickup is within the injection bump). Figure 7 shows the position oscillation and spectrograms which indicate the horizontal and vertical tunes.

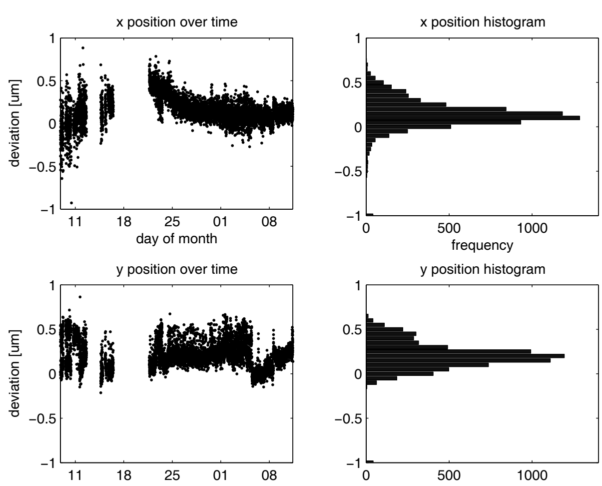

Figure 5: Position stability during one month

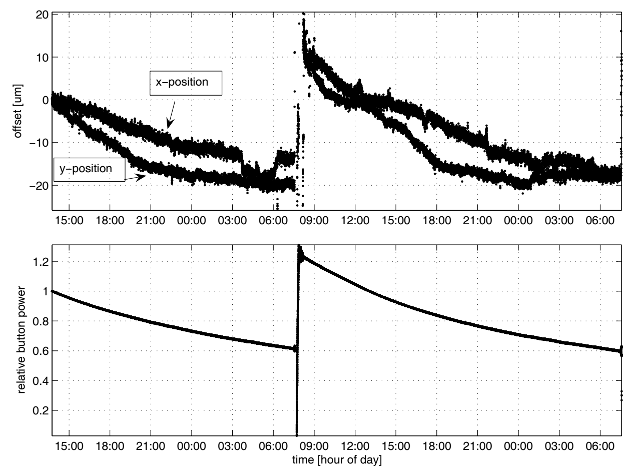

Figure 6: Motion of the beam during decay of the beam current at SRS

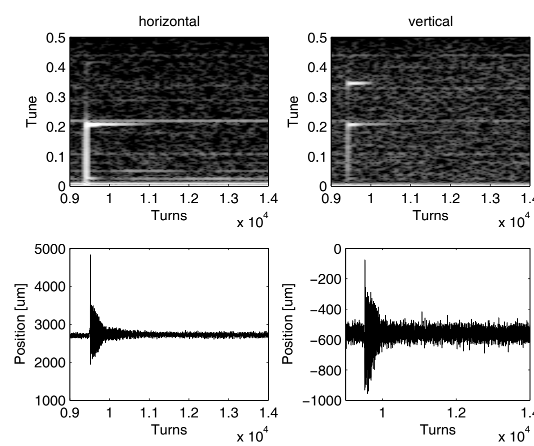

Figure 7: Tune measurement from TBT data of an injection kick

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REFERENCES

[1] U. Mavric, “Innovative RF Design Unites Benefits of Multiplexed and Multichannel System”, in *Proceedings of the 11th Beam Instrumentation Workshop Knoxville 2004*