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MEASUREMENT OF TWO BEAMS POSITIONS WITH BUTTON BPM*

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Abstract

Modern BPM processors utilize digital processing of the beam induced signals. The information on the signal amplitudes is used for the delta over sum calculation of the beam position, while the readily available phase information is usually discarded. We have experimentally tested measurement of the individual positions of two beams propagating in the common beampipe utilizing both phase and amplitude data. The proposed method can be used for the energy recovery linacs and colliders.

INTRODUCTION

Energy recovery linacs (ERL) are considered as next step in development of accelerators with record parameters such as luminosity for the colliders and brightness for the synchrotron radiation light sources.

The essence of the ERL operation implies that at least two beams (accelerated and decelerated) are co-propagating in the same vacuum vessel, and each beam has its own trajectory with more beams co-propagating in the common accelerator section. The conventional beam position monitors (BPM) will measure only "average" trajectory but not that of an individual beam, unless the time separation between bunches is so large that one can resolve individual bunches [1]. Unfortunately, it is not always possible. To overcome the problem, we proposed to utilize phase information of the signal induced on the pick-up electrodes by the circulating beams [2, 3]. Calculations show that the phase difference is directly proportional to the relative displacement of two beams.

The average position of two beams can be found using conventional delta over sum calculations

$$\frac{\delta_1+\delta_2}{2}=\frac{1}{S}\frac{A_{up}-A_{down}}{A_{up}+A_{down}}, \qquad (1)$$

where $\delta_{1,2}$ are beams displacement, $A_{up,down}$ are amplitudes of the signal on the electrodes, S is BPM sensitivity coefficient.

The phase shift between two channels is proportional to the positions difference

$$\Delta\varphi = S(\delta_1-\delta_2)tan(\omega\Delta t_{12}/2). \qquad (2)$$

This approach requires measurement of the initial phase shift between channels and suppression of the phase drifts.

EXPERIMENTAL TESTS

The tests were performed on the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory during Run24 utilizing protons at injection energy. RHIC has 120 buckets with 110 filled during regular operations. The arrival time to the common section can be adjusted using phasing of the RF cavities. Wall current monitor is utilized to monitor the charge in the individual bunches. The relativistic parameter β was calculated from the revolution frequency and ring circumference.

RHIC has two rings called blue and yellow for counter-propagating beam. Three Libera Electron Single Pass E BPM receivers [4] are placed in the common section where two beams are separated vertically to avoid collision. The vacuum chamber is round with 50 mm diameter. The button configuration is straight: top-bottom and inside-outside. The positions of the BPMs relative to the center of the straight section are -6.5, 1.1 and 6.5 meters. The BPMs are identified as modulator (mod), amplifier (amp), and kicker (kck) according to the accelerator section names. Since the beams in the collider propagate in opposite direction, the phase shift between them depends on the location of the BPM. For collision point coinciding with the canter the phase shifts are 2.58, -0.39, and -2.53 radians. The measured phase shifts were 2.45, -0.49, and -2.67 radians.

The blue ring has buckets 1-56 filled and yellow ring has buckets 29-84 filled. This way we have three regions of equal duration: a) only blue ring beam, b) both yellow and blue ring beams, c) only yellow ring beam. Regions a and c were used for conventional beam position measurement and for the measurement of the phase offset between channels in BPM. Region b was used for calculation of the beam position using the proposed method. The characteristic fill pattern is shown in Fig. 1. Variation of charge per bucket is few percent.

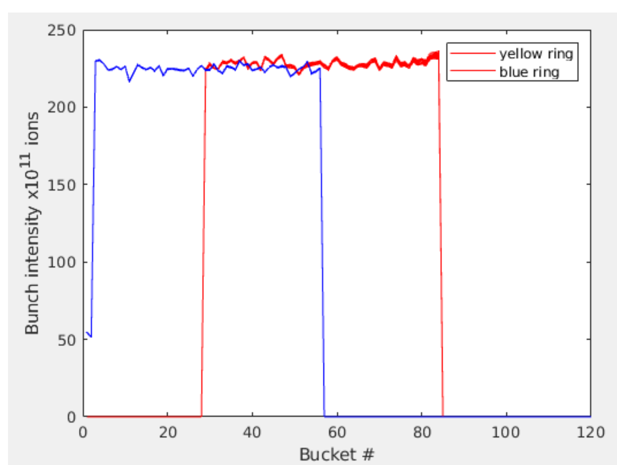

Figure 1: Fill pattern of two rings during experiment.

The observed signals from the pick-up electrodes of on of the kicker BPM are shown in Fig. 2. The ADC readings are fitted with sine wave with known phase advance per

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clock. The transient parts were excluded from the fit. The obtained amplitudes and phase are used for calculations.

The experimental results for the proton beams are shown in Tables 1-4. Each table has horizontal and vertical positions for the indicated BPM obtained from the regions with single beam present and two beams. The latter ones are marked with asterisk. Table 1 has data for the nominal set-up. Table 2 has data for the yellow beam shifted horizontally by 1 mm in positive direction. Table 3 reflects the measurement when the blue beam was also shifted vertically by 1 mm in the negative direction. Table 4 shows measurements with refilled rings with different cogging phase defining the arrival time to each BPM.

Table 1: Measured Beam Positions for Nominal Set-up

BPM	X [mm]	X* [mm]	Y [mm]	Y* [mm]
Blue mod	0.43	0.47	5.02	3.97
Blue amp	-0.27	-0.18	4.17	4.86
Blue kck	0.06	0.79	3.71	4.62
Yellow mod	0.08	-0.02	-5.25	-4.01
Yellow amp	0.31	0.29	-4.92	-5.13
Yellow kck	-0.07	0.39	-5.41	-3.36

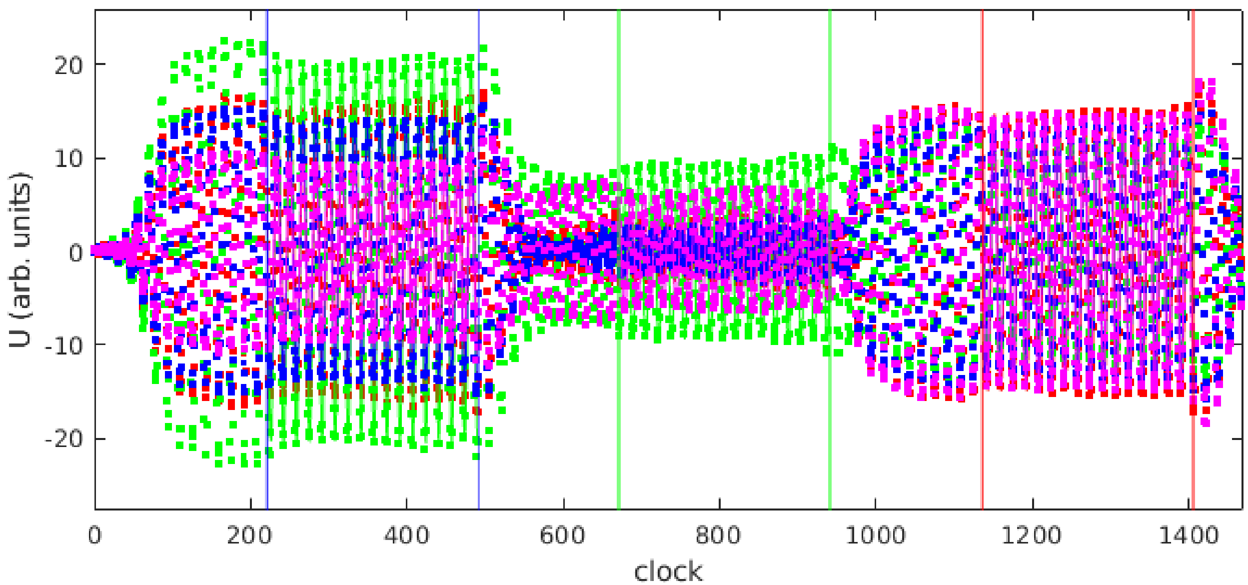

Figure 2: Traces of the beam signals from four pick-up electrodes. Three regions as well as transients are clearly visible. The a) region is between blue lines, the b) region is between green lines (amplitudes are lower due to the interfering), and the c) region is between red lines.

Table 2: Measured Beam Positions for the Yellow Beam Shifted Horizontally

BPM	X [mm]	X* [mm]	Y [mm]	Y* [mm]
Blue mod	0.25	0.07	4.82	5.56
Blue amp	-0.64	-0.69	5.28	6.34
Blue kck	-0.15	0.16	5.17	6.26
Yellow mod	1.27	1.04	-5.27	-3.45
Yellow amp	1.39	1.62	-3.45	-4.99
Yellow kck	1.03	1.22	-5.47	-2.42

It should be noted that the kicker BPM shows the largest discrepancy between two measurements. Most likely it is due to not equal fill and the phase shift between two beams of 153 degrees. Such phase shift substantially reduces the amplitude of the signal as it can be seen in Fig. 2 and make is more prone to errors caused by subtarction of two large numbers.

Table 3: Measured Beam Positions with both Beams Shifted

BPM	X [mm]	X* [mm]	Y [mm]	Y* [mm]
Blue mod	0.16	-0.11	3.91	5.29
Blue amp	-0.56	-0.49	4.38	5.27
Blue kck	-0.18	-0.09	4.21	6.61
Yellow mod	1.33	0.90	-5.19	-2.9
Yellow amp	1.45	1.46	-4.87	-4.76
Yellow kck	0.98	0.93	-5.38	-1.39

The 0.1 degrees shift in the cogging phase corresponds to the 12 degrees (0.21 radians) phase shift at the observation frequency. We have measured 0.25 radians phase change.

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Table 4: Measured Beam Positions with Changed Cogging Phase

BPM	X [mm]	X* [mm]	Y [mm]	Y* [mm]
Blue mod	0.38	0.38	4.90	5.48
Blue amp	-0.56	-0.44	5.33	6.14
Blue kck	-0.12	1.22	5.26	4.91
Yellow mod	0.03	-0.07	-5.30	-4.27
Yellow amp	0.31	0.29	-4.90	-4.87
Yellow kck	-0.09	1.02	-5.48	-0.76

With shifting of the cogging phase, the phase difference between the yellow and blue beams is 167 degrees for kicker BPM. The signal amplitudes fell fivefold and there is significant error in position determination with two beams being present.

CONCLUSION

We have successfully tested the proposed method utilizing phase information for measurement of the positions of two beams propagating in the common pipe. There is good agreement between the obtain data and conventional technique for a single beam. There is increase in the error when the beams are almost in the opposite phases.

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