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Remnant voltages in the RHIC storage system during acceleration: PART II

R. Connolly

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Collider Accelerator Department
Brookhaven National Laboratory

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INTRODUCTION

An earlier tech note [1] gave the result of a calculation of the storage cavity voltages during beam acceleration. A remnant peak voltage, V_b, of about 1.0 kV will exist in a cavity immediately after the passage of a single 4-ns long bunch, containing a charge of 1.1 x 10^{-8} C. During acceleration a damping loop is inserted into the cavity. This lowers the Q to 420 giving an exponential decay time of the cavity voltage of 0.68 μs. With 57 bunches in the ring the time between bunches is 0.22 μs so the voltage from a bunch will decay by 28% before the next bunch arrives.

In ref. 1 the total cavity voltage acting on each beam bunch was found by adding all of the contributions from the previous bunches in phase. It was assumed that the separation between adjacent beam bunches was an integer multiple of the rf period of the cavity. The voltage in each cavity at the time of a bunch arrival was calculated to be 2.6 times the single-bunch excitation voltage. This is not correct.

Voltages excited by consecutive bunches do not add in phase. The tuners will be positioned so the frequency with the damping loop withdrawn from a cavity is a harmonic of the bunch frequency. When the loop is inserted the resonant frequency increases by 720 kHz making the time interval between bunches 44.16 rf periods of the cavity . Between beam bunches the voltage from the previous bunch will decay by 28% but will also advance in phase by 58°.

SINGLE-BUNCH EXCITATION OF A CAVITY

Figure 1 is a phasor diagram showing the voltage contributions from the last eight bunches when the next bunch is centered in a cavity. The total cavity voltage and phase is found by summing the contributions from all of the previous bunches. This is done in the table for the previous 20 bunches. Column 1 gives the total phase shift of the voltage from each previous pulse with respect to the incoming bunch. The voltage amplitude is given in column 2 in units of the single-bunch excitation peak voltage. The in-phase and quadrature components of each voltage are given in columns 3 and 4. The voltage components are summed at the bottom of each column.

At the time that a bunch is centered in a cavity the voltage from all previous bunches has an amplitude of $0.83V_b$ and is 102° advanced with respect to the bunch. This number of 0.83 is to be compared to 2.6 calculated in ref. 1.

The total voltage that acts on the particles in a bunch as it passes through a cavity is the sum of the remnant field and the self voltage induced by the bunch as it travels across the gap. The self-induced voltage from a parabolic bunch is,

$$V(t) = \frac{3q}{2CD}\left[\frac{8}{D^2\omega^3}\sin\omega\left(t+\frac{D}{2}\right) - \frac{4}{\omega^2 D}\cos\omega\left(t+\frac{D}{2}\right) - \frac{8t}{\omega^2 D^2}\right]$$

where ω is the angular frequency of the cavity, D is the equivalent full width of the bunch, C is the capacitance of the equivalent parallel RLC circuit, and q is the charge in the bunch. This equation is the result of doing the integration given by eqn. 9 in ref. 1.

A 4-ns wide bunch passing through the cavity with a gap of 30 cm produces an excitation signal 4.7 ns wide. Figure 2 plots the self-voltage as a function of time as a 4.7-ns-long parabolic bunch passes through the cavity. The remnant voltage from previous bunches is plotted in fig. 3 and the two curves are added together in fig. 4. For this case the maximum gap voltage during bunch passage is about 0.25 q/C. This is 770 V for the case of $q=1.2\times10^{-8}$ C and C=3.9 pF.

VOLTAGE IN A COMMON CAVITY

The single-cavity results given above apply to the cavities in the individual rings. Several cavities will be in the interaction region and will have both beams passing through them. The plan now is to have four common cavities and three cavities in each of the individual rings. Figure 5 shows the placement of the common cavities. All four will be on one side of the interaction point and the distance between the interaction point and the closest cavity will be 2.75 $\beta\lambda$.

Each beam bunch traveling from right to left (clockwise) will see its self voltage and a remnant voltage equal to twice that shown in fig. 3. This is because the common cavities are excited by twice as many bunches as the single-ring cavities. Each bunch traveling in the opposite direction (counter-clockwise) experiences these two voltages plus the voltage added to the cavity by the recent passing of the bunch that it meets in the interaction region.

The time intervals between the clockwise bunch and the counter-clockwise bunch in the four common cavities are 5.5, 6.5, 7.5 and 8.5 rf periods. The counter-clockwise bunch passes through each common cavity an average of 7 rf periods after the clockwise bunch. Thus the residual voltage has decayed to a value of 0.95 V_b and has shifted 9°. Figures 6a and 6b show the total cavity voltages during bunch passage for the clockwise bunch and for the counter-clockwise bunch.

Finally each clockwise bunch sees a total voltage of 3 times the plot in fig. 4 plus 4 times the plot in fig. 6a. This result is shown in fig. 7. Similarly each counter-clockwise bunch sees a total voltage of 3 times plot 4 plus 4 times plot 6b. This result is shown in fig. 8. The maximum total voltage experienced by any of the beam particles is about 3.5 times q/C, seen by the last portion of the counter-clockwise bunches. For a bunch charge of 1.2×10^{-8} C this voltage is 11 kV.

REFERENCE

1. R. Connolly, "Remnant Field Levels in the RHIC Storage System During Acceleration", RHIC/RF-15, (Brookhaven National Laboratory, 1992).

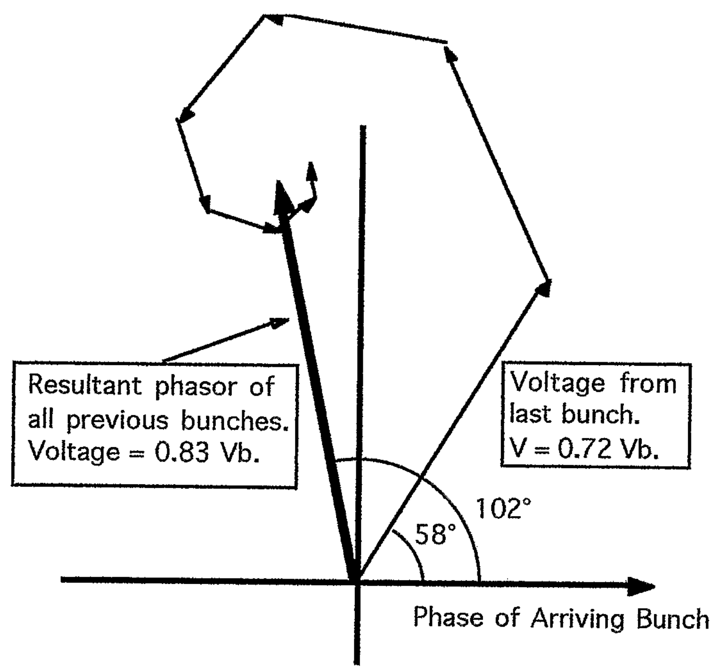


Fig. 1. Between beam bunches the voltage from the previous bunch decays by 28% and advances in phase by 58°. This figure shows the contributions to the remnant voltage by the last 8 bunches and also shows the total remnant voltage. All angles are shown with respect to the phase of the arriving beam bunch.

PHASE SHIFT (radians)	VOLTAGE (V_b)	IN-PHASE VOLTAGE (V_b)	QUADRATURE VOLTAGE (V_b)
1.005	0.720	0.386	0.608
2.010	0.518	-0.220	0.469
3.015	0.373	-0.370	0.047
4.020	0.269	-0.172	-0.207
5.025	0.193	0.060	-0.184
6.030	0.139	0.135	-0.035
7.035	0.100	0.073	0.069
8.040	0.072	-0.013	0.071
9.045	0.052	-0.048	0.019
10.050	0.037	-0.030	-0.022
11.055	0.027	0.002	-0.027
12.060	0.019	0.017	-0.009
13.065	0.014	0.012	0.007
14.070	0.010	0.001	0.010
15.075	0.007	-0.006	0.004
16.080	0.005	-0.005	-0.002
17.085	0.004	-0.001	-0.004
18.090	0.003	0.002	-0.002
19.095	0.002	0.002	0.000
20.100	0.001	0.000	0.001
		TOTAL VOLTAGE	TOTAL VOLTAGE
		-0.176	0.814

This table shows the phase and amplitude of the voltages left the in a cavity by the previous 20 bunches at the time a bunch is centered in the gap. Voltages are given in units of the single bunch excitation V_b. The first 8 of these vectors are shown added in fig. 1. The components of the resultant voltage in fig. 1 are found by summing the voltages in columns 3 and 4.

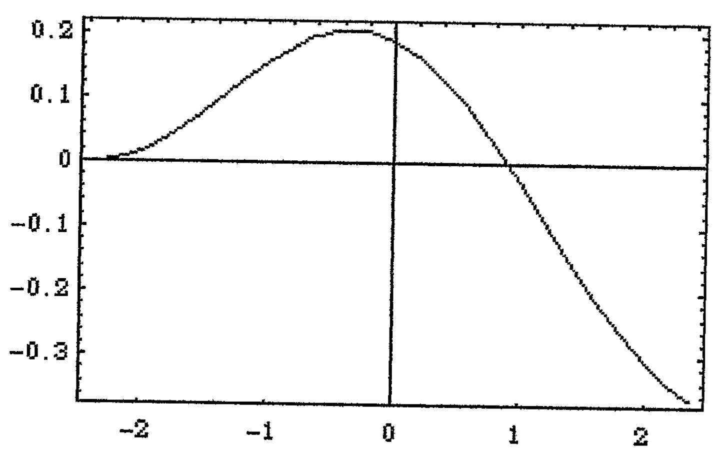


Fig. 2. Self voltage of a single 4.7-ns bunch during the time that it is passing through the cavity. The X-axis is in units of ns and the Y-axis is in units of q/C. On all of the plots t=0 is when the bunch is centered in the cavity gap.

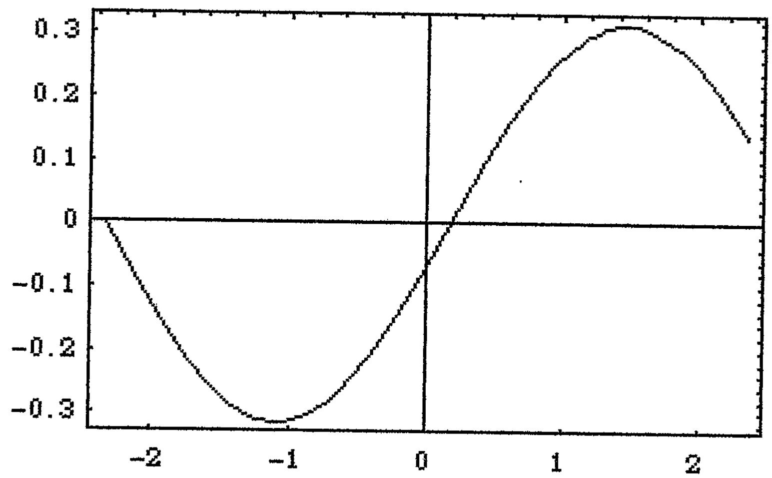


Fig. 3. Remnant voltage in a single-ring cavity from the previous 20 bunches.

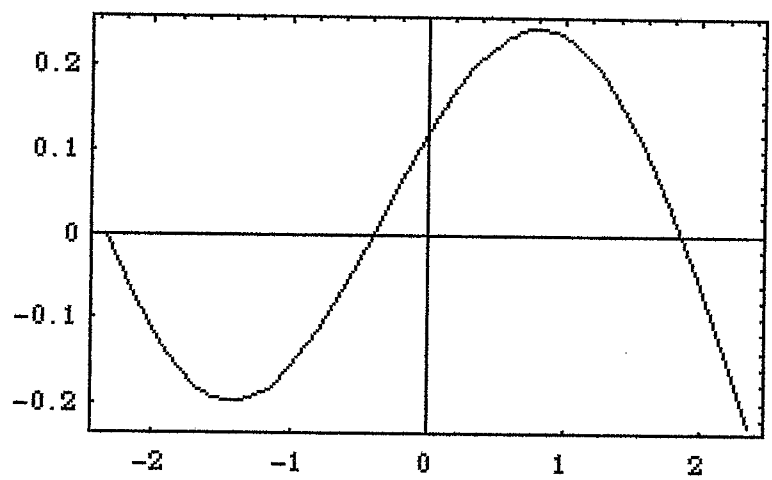


Fig. 4. Total voltage seen by one bunch in a single-ring cavity.

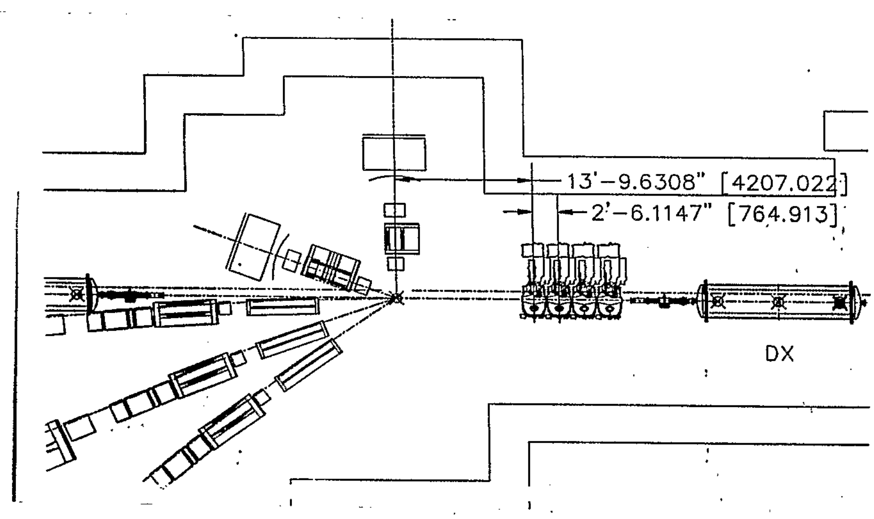
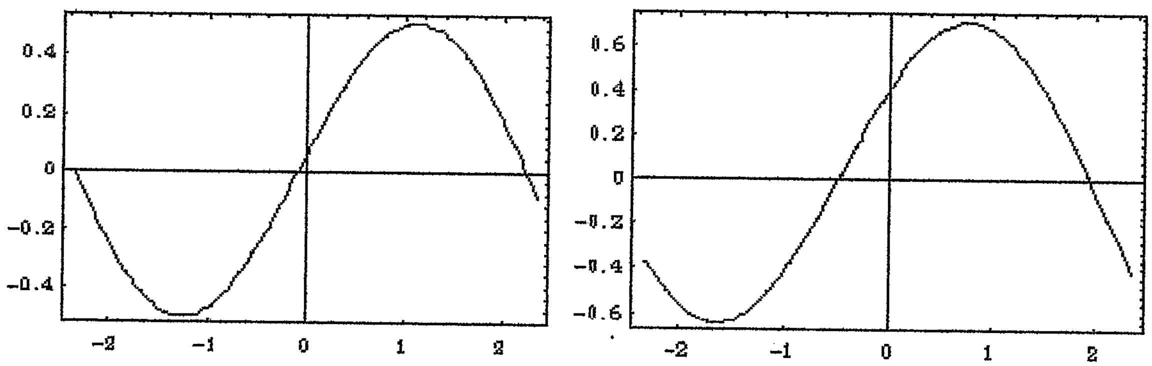


Fig. 5. Placement of common cavities in the interaction region.



Figs. 6a and 6b. Total voltage seen by a clockwise (counter-clockwise) bunch in one of the common cavities.

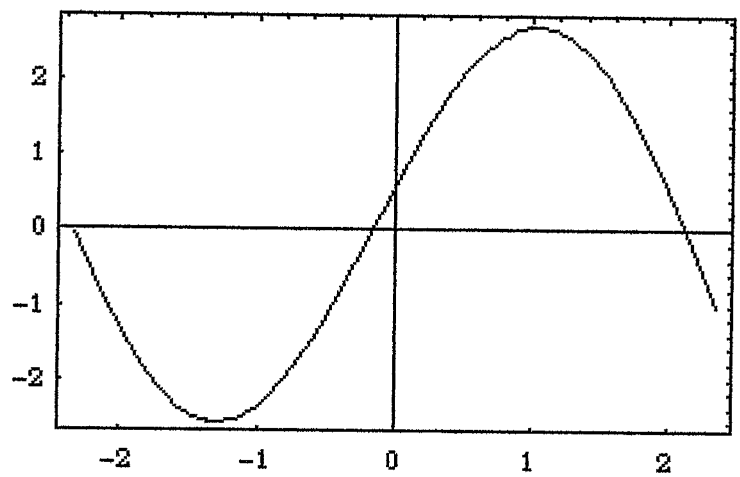


Fig. 7. Total voltage per revolution seen by a clockwise bunch.

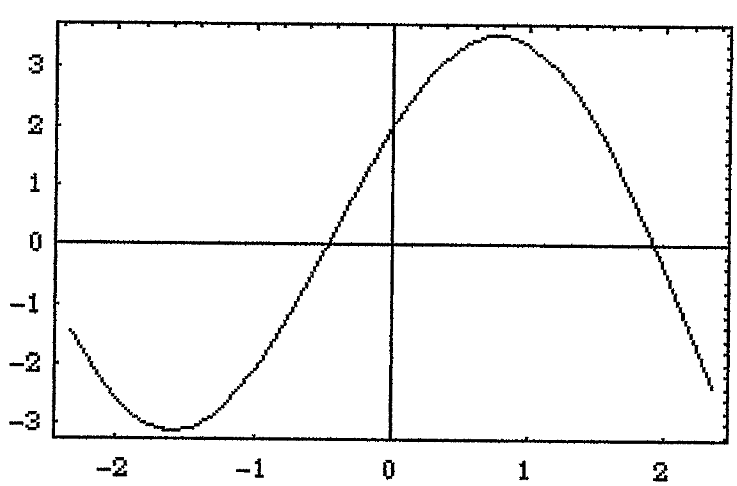


Fig. 8. Total voltage per revolution seen by a counter-clockwise bunch.