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Longitudinal emittance growth in the presence of transient beam loading

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Abstract

Transient beam loading effect from storage cavities ($196MHz$) on longitudinal emittance through transition is investigated with computer simulation. To have less than 10% emittance blowup after transition, the induced voltage due to shunt impedance should be kept below $10kV$.

Two major *RHIC* RF systems are $26.7MHz$ accelerating cavities and $196MHz$ storage cavities. The accelerating system captures injected beams from *AGS* and accelerates them, with exception of proton beams, through transition to designed top energy for storage. The storage cavities then capture the beams at top energy and store them for experiments. We can divide this cycle into 4 regions: capture at injection, acceleration through transition to top energy, transfer from accelerating cavities to storage cavities and storage. In these regions, the induced voltage on the storage cavities acts back on the beam to distort particle distributions, hence to increase the emittance at the best and to cause beam loss at the worst.

Proton beams are exceptions. They are injected above transition, thus avoiding the complications at transition region. However, their nominal capture voltage is rather low, at $12kV$. This problem can be eliminated by reducing the bunch length by a half in *AGS*, which increases the capture voltage by a factor of approximately 16.

This note studies gold beam longitudinal emittance growth in the presence of transient beam loading from 8 storage cavities seen by both beams in two rings, with emphasis at transition region. First, the bunch length is shortest around transition region, so the beam induces more voltage. Second, phase stability is at its weakest in the transition region, any perturbation can blowup the emittance greatly. Should the induced voltage be kept permissibly low at transition region, it does not pose a serious concern over other regions.

The longitudinal emittance is defined as an area in the phase space which contains 95% of the particles in the bucket. One way to find the emittance away from transition is to draw contours in the phase space, and find the area under a contour which encompasses 95% of the particles in the bucket. Since we simulate a finite number of particles, emittance measurements inevitably fluctuate slightly even under ideal conditions (see Figure 1), more if the bunch starts to tumble.

At the injection the capture voltage is $215kV$. The induced voltage from storage cavities will distort particle distributions and introduce high frequency structures. However, the effect is rather small. The emittance has only 9% increase with as much as $215kV$ induced voltage.

Previous studies [1] have shown that a γ_{tr} jump (see Figure 2) of 0.8 unit in a time of $60ms$ can significantly reduce chromatic nonlinear effect, space-charge mismatch and microwave instability to make a particle lossless transition. We use computer simulation to investigate the emittance growth as a function of magnitudes of induced voltage on the storage cavities, which are assumed to be tuned on the beam revolution frequency.

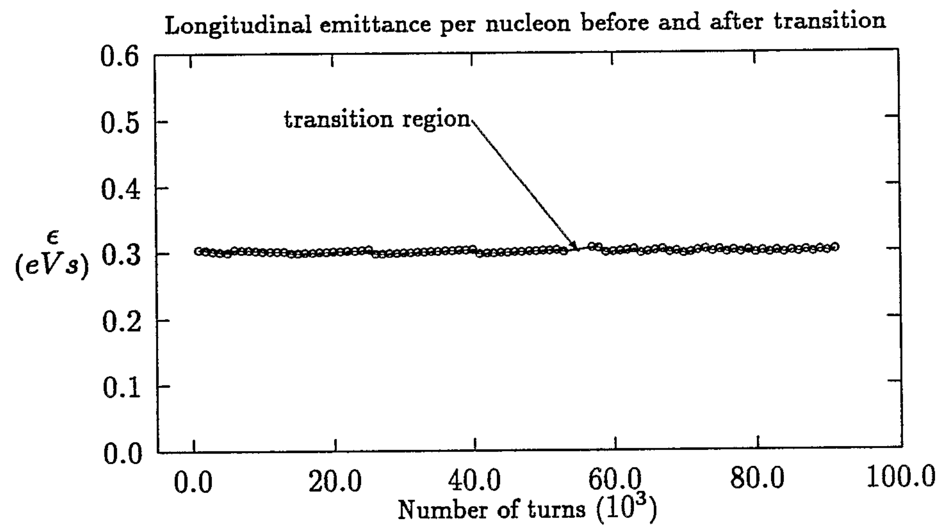

Figure 1: Tracking under ideal conditions, *i.e.* without chromatic nonlinearity

There are two basic offending induced voltages exerted on a given bunch of particles, both are proportional to the total charge of the bunch. One is long range wake field generated by previous bunches. For a tuned cavity, the long range wake field is in phase with respect to the beam. The magnitude depends on the shunt impedance ($\frac{R}{Q}Q$) of the cavity, which can be controlled by de-Qing. Another is the self-field— wake field induced by the bunch itself which depends on the equivalent capacitance of the cavity. The basic theorem of beam loading is that a bunch sees only half of its induced voltage (see Figure 3). Ideally one should model the self-field with a self-consistent way, that is to take the beam and the cavity as a whole system, to calculate the cavity response from the beam shape which in turn is influenced by the cavity response. However, a simple model of a square beam is adopted to compute the self-field which is assumed to be a constant throughout. The full bunch length is assumed to be $5ns$ roughly corresponding to the bunch length at transition.

We start off to find the emittance growth when the long range wake field is zero, so it is a case when only chromatic nonlinear effects, γ_{tr} jump and beam self-field are considered and

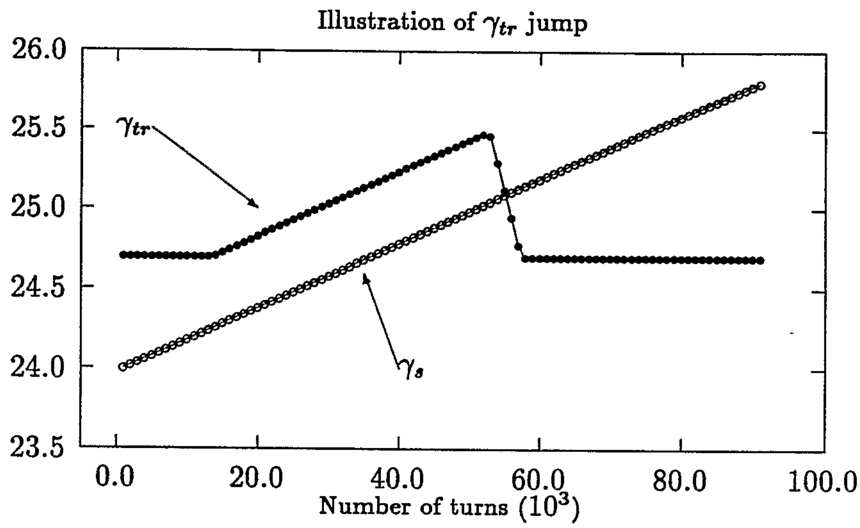

Figure 2: Relationship between γ_{tr} and γ_s

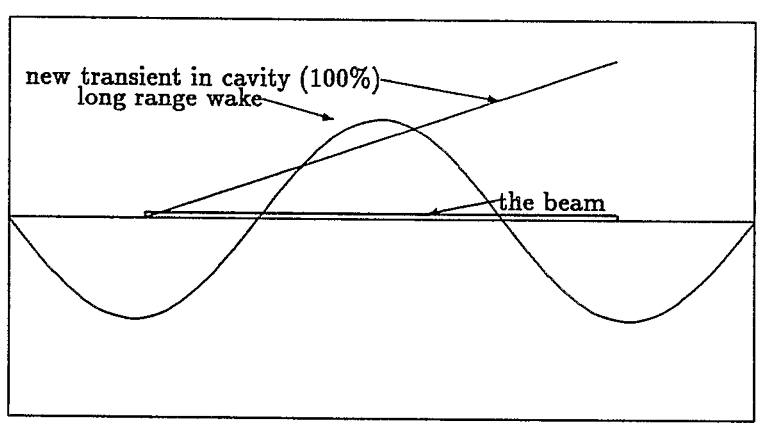

Figure 3: Offending induced voltages.

on the accelerating cavities to debunch the beam, then suddenly increase the voltage to rotate beam in order to fit in the storage bucket. A large emittance means long bunch length, in order to reduce the bunch length, the debunching voltage has to be low which may reach the threshold of coasting beam instability. It also means more of the nonlinear region in the bucket is populated with particles, which leads to more particle losses during transfer process since the storage bucket can't capture them. A large emittance requires more matching voltage on the storage cavities, which may be difficult to achieve if the ramp time is short . So we should keep the emittance blowup as little as possible.

In conclusion, a large induced voltage has a detrimental effect on the beam longitudinal emittance. The studies suggest to keep the induced voltage below $10kV$ which corresponds to about 10% increase in emittance. The implication on the requirement of the shunt impedance of the cavities will appear in other reports.

Acknowlegement

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References

[1] J. Wei. Transition crossing in the rhic. AD/RHIC 84, Brookhaven National Laboratory, 3 1991.

increase in the emittance (see Figure 6).

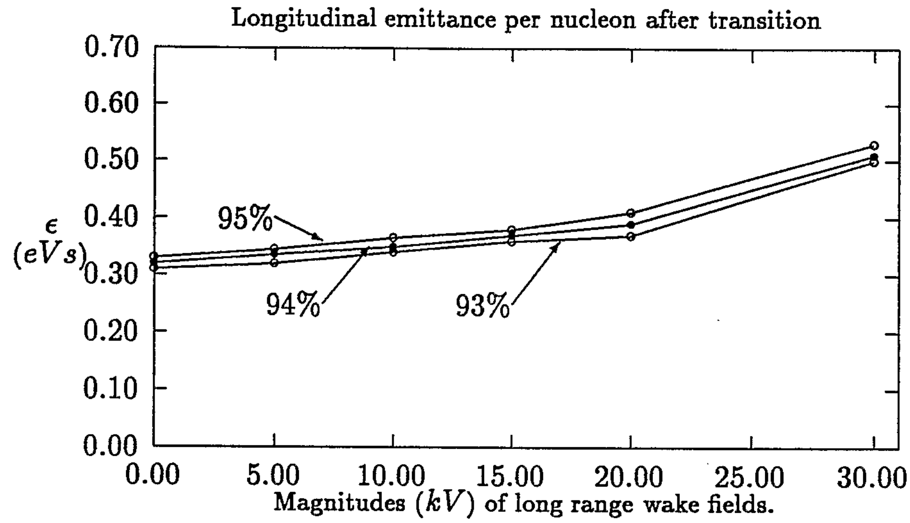

Figure 6: Variation of emittance per nucleon with different percentages of particles included.

Naturally, to find the emittance growth rate due to long range wake field, we need only to compare the emittance at different magnitudes of induced voltage to that when induced voltage is zero. Note 95% of the particles are used in the definition of the emittance.

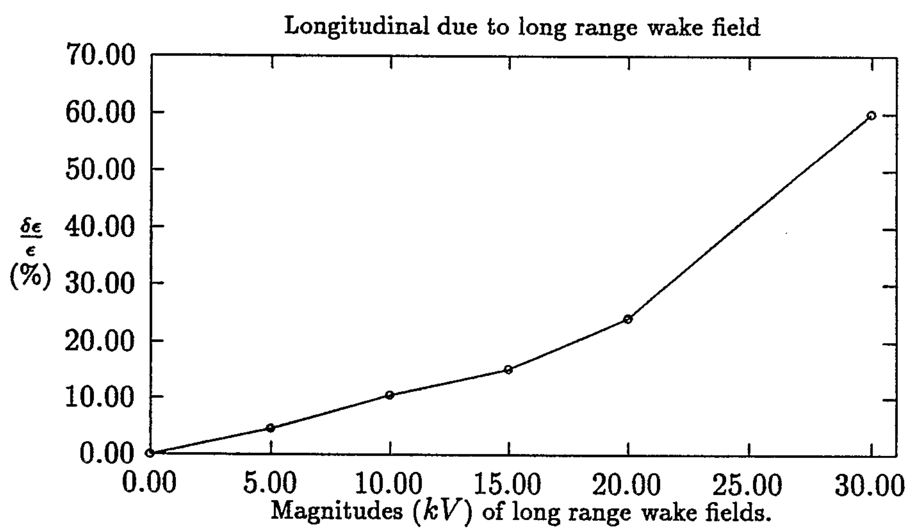

Figure 7: Emittance growth rate due to long range wake field.

The larger the emittance of a bunch in the accelerating bucket, the harder it is to transfer the bunch into the storage bucket. The transfer scheme is to adiabatically lower the voltage long range wake field is neglected. We find a growth of approximately 10% (see Figure 4).

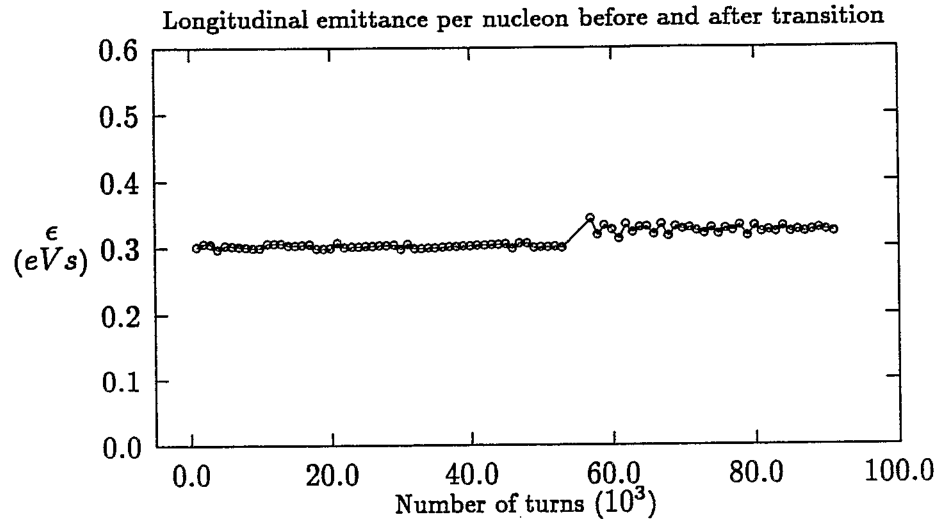

Figure 4: Tracking with chromatic nonlinearity.

Then we gradually increase the magnitudes of the long range wake fields up to $20kV$ in increments of $2.0kV$, and monitor the emittance The emittance after transition starts to grow as the magnitude of long range wake field increases.

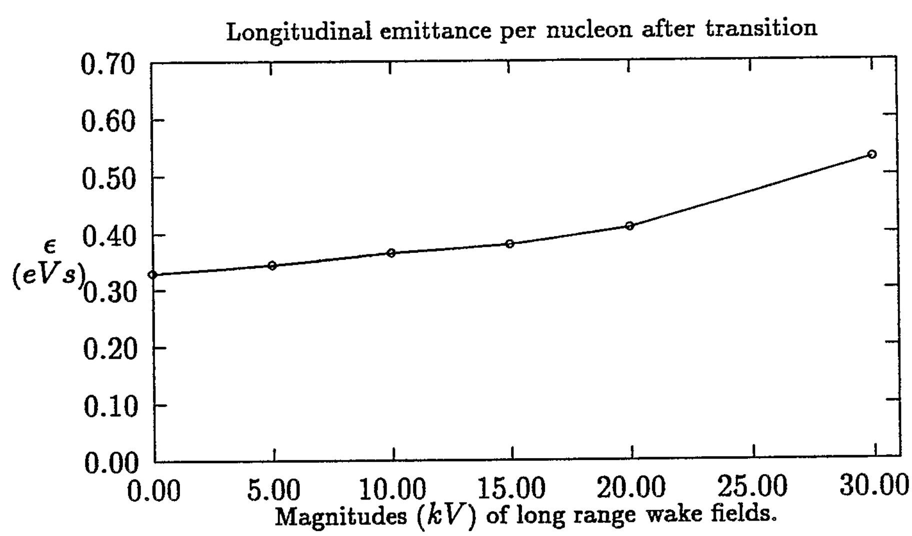

Figure 5: Emittance per nucleon after transition varies with magnitudes induced voltages.

The emittance after transition depends critically on what percentage of particles is included in the definition of emittance. A one percent difference may result in ten percent