Experimental Study of Transition Crossing at AGS

Jie Wei, BNL, May 4, 1996

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Acknowledgements:

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I. Introduction

Transition energy: energy at which particles of different momenta have the same revolution frequency.

(No longitudinal focusing, non-adiabatic synchrotron motion, emittance growth, instabilities, beam loss)

Single-particle effects:

- mismatch in phase switching timing, non-linear bucket
- chromatic nonlinear effects

Multi-particle effects:

- bunch mismatch due to beam self fields
- combination of self fields and nonlinearity
- microwave instability

Cure:

- avoid transition energy
  (un-conventional machine lattice)
- γ_T-jump by pulsing quadrupoles
  (distort lattice, enhance α_1, increase dispersion)

History:

- Discovery of the transition energy

  N.M. Blackman and E.D. Courant, Rev. Sci. Instr. **20** 596 (1949)

- Discussion on chromatic nonlinear effect

  K. Jøhnson, Proc. CERN Symp. High-Energy Accel. and Pion Phys. (1956)

- First successful transition crossing on CERN PS and BNL AGS (1960s)

  ...

- Still needs to cross transition in newly designed machines

  Relativistic Heavy Ion Collider (RHIC)

  (superconducting magnets, slow ramping rate, enhanced chromatic effects)

  Fermilab Main Injector

- More recent theoretical studies:

  K. Takayama, S.Y. Lee, J. Wei, et. al.

- More recent experimental studies:

  P. Faugeras, et. al., second order effects in SPS, 1979

  ...

  J. Wei, M. Brennan, ei. al., experiments done at AGS since 1993

II. Results of Experimental Study

1. Measurement of nonlinear momentum compaction factor α_1

$$\beta^2 \dot{B}\ \Delta t = -\left(\alpha_1 + \frac{1}{2}\beta^2\right) B\ \frac{\Delta p}{p}$$

- using “pencil” beam with small $\Delta p/p$;
- vary $\Delta p/p$ by displacing the radial orbit;
- determine transition timing (Δt) by measuring the minimum beam loss when varying the time of phase switching.

Beam loss vs. syn. phase switching time

Table 1: Measured AGS γ_t, α_1, and momentum aperture at various γ_t-jump quadrupole (I_Q) and sextupole (I_S) settings.

(I_Q, I_S) (A)	(0, 0)	(1700, 0)	(1700, 100)
γ_{t0}	8.45	10.12	10.12
α_1	2.5	90	16
$\Delta p/p\|_{ap}$ $(\times 10^{-3})$	± 7.9	± 4.7	± 4.3

2. Effects of chromatic nonlinearity

(Growth in longitudianl beam emittance)

Beam loss vs. crossing rate $\dot{B}$

Beam loss vs. peak rf voltage

3. γ_T-jump and nonlinearity enhancement

- γ_T-jump improves crossing efficiency by increasing the effective crossing rate
- γ_T-jump usually distorts lattice, enhancing α_1 and dispersion

4. reduction of nonlinearity using sextupoles

III. Comparison with MAD and TIBETAN Simulations

1. α_1 and dispersion evaluation using MAD

Table 2: MAD calculation of AGS γ_{t0}, α_1, α_2 and maximum dispersion $\eta_x|_{max}$ at the γ_t-jump quadrupole and sextupole settings corresponding to Table 1.

(I_Q, I_S) (A)	(0, 0)	(1700, 0)	(1700, 100)
γ_{t0}	8.45	10.12	10.12
α_1	2.2	76	19
α_2	8.9	-2.7×10^3	-1.6×10^3
$\eta_x\|_{max}$ (m)	2.2	8.6	8.6

2. Longitudinal simulation using TIBETAN

- Using experimentally extracted α_1 and machine parameters, simulate transition crossing using TIBETAN under the same experimental condition
- Compare simulated mountain-range plots with experimental digitized beam profile data, using the same post-analysis codes (GT_ANALY)

IV. Conclusions

- Although γ_T-jump in AGS improves transition crossing efficiency for high intensity beams, it enhances chromatic nonlinear effects (α_1).

- The sextupoles can be excited to greatly reduce α_1, hence improving longitudinal crossing at transition. However, the current scheme results in large dispersion.

- An optimization in γ_T-jump scheme and sextupole arrangement can greatly improve AGS operation at transition.

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