RHIC instabilities at transition crossing

Xiaofeng Gu, Wolfram Fischer, Michael Blaskiewicz, Michiko Minty, Christoph Montag, Vadim Ptitsyn

Thanks to the Committee for invitation!

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Outline

- Introduction
- Observation
- Methods
- Summary
Operated modes (beam energies):
- U – U 100 GeV/n
- Au – Au 3.8/4.6/5.8/10/14/32/65/100 GeV/n
- d – Au 9.8/19.5/31.2/100 GeV/n
- Cu – Cu 11/31/100 GeV/n
- p↑ – p↑ 11/31/100/205/250 GeV
- He-3 – Au 100 GeV/n
- p↑ – Al 100 GeV/n
- p↑ – Au 100 GeV/n
- Ru – Ru 100 GeV/n
- Zr – Zr 100 GeV/n

Achieved peak luminosities:
- Au–Au (100 GeV/n) 155×10^{26} cm^{-2} s^{-1}
- p↑–p↑ (250 GeV) 245×10^{30} cm^{-2} s^{-1}

Performance defined by:
1. Luminosity L
2. Proton polarization P
3. Versatility (species, E)
Instability during Transition

→ In RHIC, all ions above 23 GeV except proton have to cross transition energy, with slow superconducting magnet ramping rate

→ **Single particle effects** -> chromatic non-linearity -> different momentum particle to cross transition at different times

→ **Multi-particle effects** -> bunch shape mismatch to RF bucket (induced by low frequency self fields) and microwave instability (higher frequency self fields)

→ These multi-particle effects will increase the momentum spread, enhancing the chromatic nonlinear effect and leading to particle loss

→ **Electron clouds** -> bunches are short at transition triggering e-cloud formation -> e-clouds lower the stability threshold given by the machine impedance and enhanced by electron clouds

→ In RHIC, instability has limited total bunch intensities in the past (not presently)
Two time scales to characterize transition crossing

The non-adiabatic time: not described by adiabatic Hamiltonian (longitudinal)

The non-linear time: single particle non-linearity chromatic effect (transverse)

\[
T_c = \left( \frac{AE_T}{ZeV |\cos(\phi_S)| \cdot \frac{\gamma_T^3}{h\gamma'} \cdot \frac{C_0^2}{4\pi c^2}} \right)^{1/3}
\]

\[
T_{nl} = \left| (\alpha_1 + 1.5 \cdot \beta_T^2) \right| \cdot \delta_{max} \cdot \frac{\gamma_T}{\gamma'}
\]
1. Beam Decay and BBB beam loss
2. IPM for Emittance
3. Coherence signal
4. Electron cloud detector
5. Longitudinal Bunch length & Shape
6. Vacuum
7. 10Hz & TBT BPM
8. Longitudinal phase tomographic reconstruction
Button BPM for coherence measurement

3 components for fast instability

2 components for slow instability

Figure 6: Time series of the 2 strongest principle components for a slower instability. The traces are offset vertically to improve clarity.

M. Blaskiewicz et al, PAC 2003

Signal used in MCR
Electron Cloud Detector


FIG. 10. (Color) Pressure increase vs time-averaged electron current density into the wall. Red dots are measured values, the black line is a linear fit [21,22].


EC signal used in MCR

U. Iriso-Arizo, et al, 2003, PAC
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The Blue instability, horizontal plane, 0.1 sec after transition.

Figure 2: Bunch intensity transmission through the transition in dependence on bunch position in the train.
Total Beam Loss (Fill18176, 4/6/2014)

- Beam Decay: 4500%/hour
- Bunched Intensity: 13%
- Transition Crossing
- BBB Beam Loss
Coherence Signal (Fill18176, 4/6/2014)

Yellow ring Coherence Signal (V)

Blue Coherence Signal (H&V)

Transition Crossing
Electron Cloud Signal (Fill18176, 4/6/2014)

Transition Crossing

Re-bucketing

Bunch Length

E-cloud

Yellow (V)

Blue (H&V)

E-cloud Signal
10Hz BPM and Mean Orbit (Fill19704, 3/17/2016)

**Yellow ring**

**Blue ring**

**Xmean**

**bpm during transition**

**Blue ring**

**Yellow ring**

Minty Michiko  2016-03-17elog
WCM and Landau Damping (Fill 19807)

- **Bunch Height**: $2.4 \times 10^{11}$
- **Bunch Width**: $2.2 \times 10^{11}$

**Blue Landau Damper – Beam Load before Transition**

**Yellow Bunches**

- **Bunch Area**
- **Bunch Height**
- **Bunch Width**
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1. **gt-jump implemented**
2. **Octupoles control**
3. **Chromaticity control**
4. **Lower Accelerator RF voltage**
5. **Landau Cavity for shape Oscillations after Transition**
6. **Split transition lattice**
7. **Feedback of quadrupole oscillations**

1. **In-situ baking**
2. **NEG**
3. **Scrubbing**
4. **Solenoid, anti-grazing rings ...**
GammaT Jump and Transition Crossing

GammaT Jump

Chrom Jump

Octupole Current

Beta function
Chromaticity --- Sextuple (Fill19765-19766, 4/13/2016)

Fill19765: Before Vertical Chrom Change

Fill19766: After Vertical Chrom Change

Yellow Emittance (V)

Beam Decay

Yellow Beam Decay

After Vertical Chrom Change

- Octupole = -15
- Octupole = -18

Yellow Emittance (V)

Accelerator Cavity Voltage (Fill 19679)

6.5% beam loss

Transition

Voltage

Phase jump

Figure 4: Average beam loss at transition as a function of the RF voltage with $b_{oct} = -3$ unit.
NEG coating started from 2005, increased the total stored charge in operation.

Notes: charge also limited by effects other than total charge (injectors, transition), dynamic pressure can be limited by single location (experiment).
Ecloud: scrubbing with Au and Proton

Scrubbing used in 2007 Au-Au operation:

7 high intensity fills in about 2 h, Reduced dynamic pressure in worst location by more than 1 order of magnitude

2011 pp operation:

Vacuum

Intensity
Au Bunch Intensity Evolution

\[ L(t) = \frac{1}{4} f_0 N \frac{N_b^2(t)}{(t)^* (t)} h(\, *, \, s, \, ) \]

- \( \gamma_t \)-jump, octupoles at transition
- scrubbing with protons
- EBIS, Booster 4\( \rightarrow \)2\( \rightarrow \)1, AGS 8\( \rightarrow \)4\( \rightarrow \)2 merge
- AGS 12\( \rightarrow \)6\( \rightarrow \)2 merge
- ultimate goal (25% more)

main limits:
- transition instability in RHIC (e-clouds)
- Machine protection

H. Huang, K. Gardner, K. Zeno, RF, et al.
Summary

- all ions except protons cross transition in RHIC, a relatively slow ramping sc machine
- observed transition instabilities with rise time as fast ~15 ms in the past
- clearly driven by electron clouds
- presently not limiting operations after implementation of a number of mitigation measures
- Used methods include gamma-t jump, octuples, fast chromaticity change, RF voltage, tune and orbit control, NEG coating of warm pipes, scrubbing over several years
More Methods for Transition Crossing Control

1. Reactive loading for less impedance

2. Rf system feedback

3. Avoiding phase jump by continuously varying phase and voltage

4. Artificial blow up longitudinal emittance

5. Using flattened rf (9MHz and 28MHz)

6. Temporarily changing the orbit circumference using programmed V and phase

7. Rf manipulation to eliminate bunch length oscillation.

8. Reduce rf voltage

9. Simulation?

Handbook of Accelerator Physics and Engineering, 2nd print. J. Wei, p286
1. Intensity Dependent Effects in RHIC, Jie Wei, BNL-66781
2. Transition Crossing in the RHIC, Jie Wei, BNL 45923
3. A First order Matched Transition Jump at RHIC, S. Peggs et al, PAC1993 p168
6. Transverse Instabilities in RHIC, M. Blaskiewicz et al, PAC 2003
10. Calibration of RHIC Electron Detectors, P. He, et al, PAC03
20. Observation of electron-ion effects at RHIC transition, J. Wei et al, PAC2005, p4087
27. A Diagnostic for Improving Transmission Through Transition in RHIC, P. Cameron, 2007
31. FEEDBACK DAMPER SYSTEM FOR QUADRUPOLE OSCILLATIONS AFTER TRANSITION AT RHIC, N. P. Abreu et al, EPAC02, p3242
32. Simulation of Electron Cloud Density Distributions in RHIC Dipoles at Injection and Transition and Estimates for Scrubbing Times, P. He, et al, PAC09
33. Measurements of fast transition instability in RHIC, V. Pitsyn et al. BNL-90793-2010-CP, IPAC10 p1638
34. Experience with split transition lattices at RHIC, C. Montag et al, IPAC10
36. More....

Thank you.