Vertical Instability in the Rapid Cycling Synchrotron (RCS) of IPNS of ANL

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Coworkers

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The RCS: Rapid Cycling Synchrotron

Circumference: 42.95 m
Injection energy: 50 MeV
Extraction energy: 450 MeV
Revolution frequency: 2.21-5.14 MHz
Tunes:
- x: 2.21
- y: 2.31
Injected pulse length: 75 us
Injected charge: $3.6 \times 10^{12}$ H-
Repeat rate: 30 Hz
Overall efficiency: 88%

Intense Pulsed Neutron Source

Injection

The 3rd cavity

Extraction

Cavity

Cavity

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The operation of RCS

- In the early ’80s, a head-tail instability was found. It was cured with the addition of sextupoles.
  \( I_{\text{Ave}}: 5 \text{ uA} \rightarrow 11 \text{ uA} \)

- The next threshold appeared to be from a vertical instability. The cure was RF cavity phase modulation (PM) later in the cycle.
  \( I_{\text{Ave}}: 11 \text{ uA} \rightarrow 15 \text{ uA} \)
Observation of beam loss with Resistive Wall Monitor

Bunch charge

with PM
no PM

PM: phase modulation
Spectrum with instability

vf_ns_2_500mV: (CH4-CH3) FFT results of 13.88 to 13.90 ms

Lower sideband

higher sideband
Conversion of beam position monitor signals

The revolution period shrinks as the bunch’s energy steps up.

In order to view the centroid motion on a turn-by-turn basis,

- BPM signals are separated into single turns,
- then for each single turn, BPM signals are converted into rf phase basis,
- then single turn BPM signals can be overlaped.
In the vertical plane, instabilities in tail only, 2 modes

Mode 0

Mode 1

Sum

Difference

50 turns BPM signals are shown
The oscillation starts from the tail
Vertical Centroid Oscillation in the Tail

Beam Position Monitor (BPM) sum signal

BPM difference signal

Sum/difference
Classical Head-Tail behavior (Garyete and Sacherer)

Classical head-tail
We turned off the sextupole to induce a head-tail at RCS

BPM sum signal

BPM difference signal
Classical head-tail at RCS

BPM sum signal

BPM difference signal

Sum/difference
No sextupole, classical head-tail

Oscillation in tail only
Tail oscillation starts before beam loss
Phase Modulation (PM) at $2f_s$ in the RCS

PM frequency 10 kHz,
PM amplitude 4.3 degree
Simulation, PM increase $\Delta p/p$

![Graph showing simulation results for PM increase](image)
Utilize the 3rd cavity

We can utilize the 3rd cavity to increase the total Vrf to increase \( \delta \)
Simulation, higher Vrf increase $\Delta p/p$

We can see that the increase of Vrf in the later cycle improves $\delta$ correspondingly.
Summary:

- The vertical instability is limited in the tail
- The characteristics of classical HT instability is different from our observation
- Investigating to use 3rd cavity to increase threshold
- Investigating electron cloud effects in RCS
The end

Thank you