Stochastic Cooling/Experiments

Mike Brennan

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- The problem
- Principle of stochastic cooling
- Technology
- Challenges
- Future(istic) possibilities

The Problem

- IBS
  - Emittance growth drives beam out of the bucket
    - Diminishes effective luminosity
    - Creates de-bunched beam, > dirty dumps
  - Can't FIX the problem (atomic scale)
    - Mitigate with bigger buckets (momentum aperture)
    - Emittance blowup strategies
    - Gap cleaning
  - Not a surprise
- Cooling can counteract IBS
  - So why wasn't cooling part of the original project scope?

RHIC Design Manual

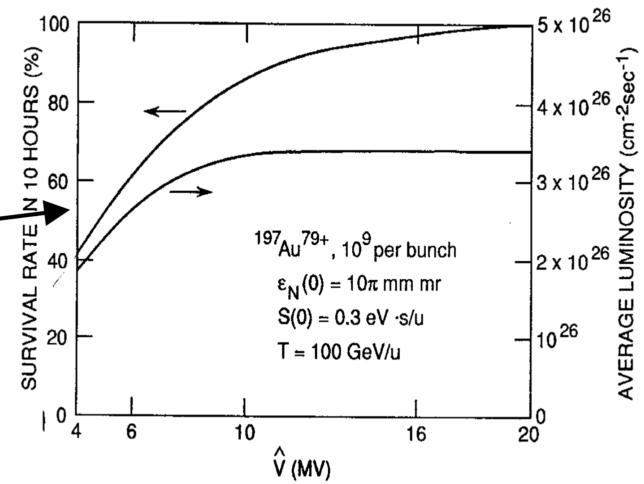


Fig. 7-3. Dependence of final beam survival rate and average luminosity on storage rf voltage after 10-hour operation, "constant voltage" scenario (courtesy J. Wei).

Stochastic Cooling's Bad Rap

- High frequency bunched-beam stochastic cooling was tried a CERN and FNAL
  - It didn't work because of coherent signals in the Schottky spectrum
  - Was abandoned at SPS and Tevatron
- The common opinion arose that bunched-beam stochastic cooling doesn't work
- Several things are different for RHIC
  - Ions have much stronger Schottky signals
  - We examined the coherent signals from gold and they aren't as bad as Tevatron and SPS
  - Technology has advanced (below, fiber optics)
  - Our scope is less ambitious (halo cooling)
  - Our PROBLEM is not going to go away

Principle of operation

- In the simplest approximation the cooling time is just,

$$\tau = \frac{N}{B\ W}$$

  – Where: N is the number of particles and BW is the system BandWidth
  – The only parameter is BW, hence high frequency, (4-8 GHz)
  – N for bunched-beam is $\left(\frac{N_{\text{bunch}}}{\ell_{\text{bunch}}}\right) 2\pi R$
  – For RHIC

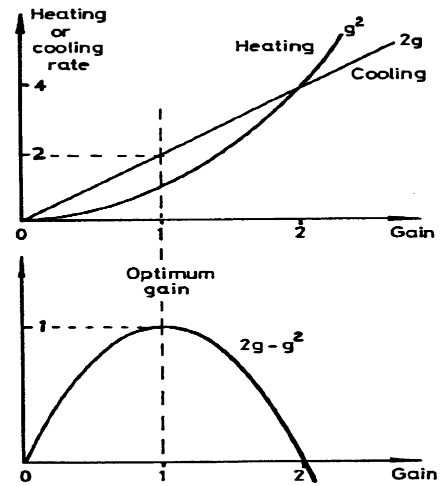
$$\tau = \frac{\left(10^9 /(c\ 5\text{ns})\right) 4\text{km}}{4\text{GHz}} = 667\,\text{sec}$$

- This simple formula is only overly optimistic by less than a factor of 10 so…should work!

Optimum Gain

- System gain is important because it determines the size of the kickers and hence the cost of the system
- Cooling rate as a function of gain,

$$\frac{1}{\tau} = \frac{BW}{N_{eff}}(2g - g^2)$$



- g=1 implies correction kick equals measured error

•Optimum gain is further reduced by insufficient "good" mixing, g_{opt}=1/5

- •"Mixing" means the redistribution of particles in the sample
- •Once the kick is applied (g=1) there is no signal to make further corrections, until mixing re-randomizes the distribution
- •In RHIC mixing is not good because eta is so small

Kicker Size for RHIC

- 100 Gev/n, Q/A=79/197, e_{long}=1 eVs all tend to make for very large kicker voltage

$$\delta E_{kick} = g_{opt}\frac{\sigma_E}{\sqrt{N_{sample}}} = g_{opt}\frac{\gamma A m_u \frac{\Delta p}{p}}{\sqrt{T_{sample}\frac{10^9}{5ns}}}$$

$$= \frac{1}{5}\frac{100 \cdot 197 \cdot 1GeV \cdot 10^{-3}}{\sqrt{125ps\frac{10^9}{5ns}}} = 800keV$$

$$Voltage = \frac{\delta E}{q \cdot \#kickers} = \frac{8x10^5}{79 \cdot 128} = 80Volts$$

$$Power = \frac{V^2}{2R} \cdot \#kickers = 64Watts \cdot 128 = 8kW$$

Halo Cooling for IBS

- If the goal is to keep the beam bunched then we don't really want to cool the core, just keep the beam from crossing the separatrix
  - Cooling of the hot part of beam goes faster
    - Better mixing
    - Better signal to noise ratio
  - For a full bucket J. Wei showed (PAC 91 pp.1866) that coasting beam theory gives the correct results for cooling rate and stability limits
  - With a full bucket the synchrotron satellites completely overlap, giving good mixing
- We're not really looking to cool the beam (that will come with the electron beam), just to keep it from getting too hot
  - I'd like to change the lingo, …….call it not stochastic cooling but stochastic refrigeration

Technology

- Pickups and kickers
- Spectra and filtering
- Fiber optic goodies
- One-turn delay possibilities
- Power amps (TWTs)

Pickup and Kicker

- We have a Tevatron pickup/kicker installed in the yellow ring at 2 o'clock
- Last year we had only the pickup
  - This allowed measurement of the spectra
  - We never moved it close to the beam
  - Observed only sum signals (longitudinal)
- Now we have the kicker also
  - Can measure beam transfer function
  - This will hopefully specify the kicker power requirement
  - In principle, we could do a demonstration of cooling, at injection for example

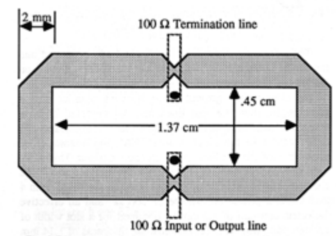


Fig. 3 Dimensions of planar loop used in the 4-8 GHz bunched beam cooling array.

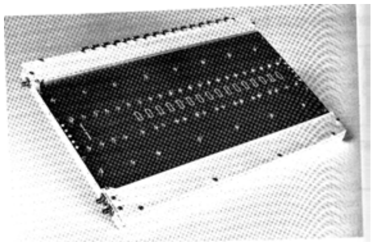


Fig. 4. Photo of 4-8 GHz planar loop array. This side faces towards the beam.

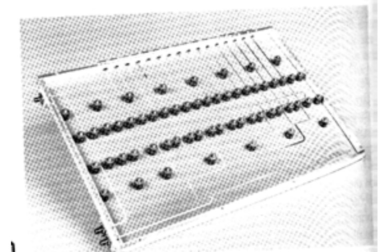
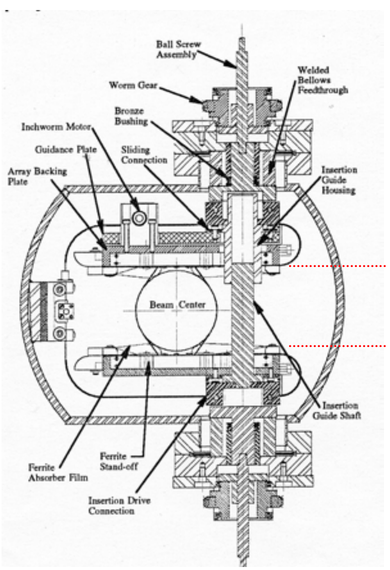


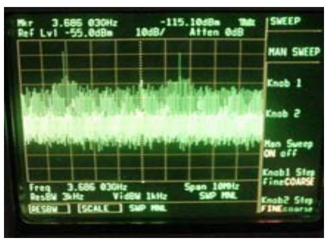
Fig. 5 Photo of the 4-8 GHz planar loop combiner board.

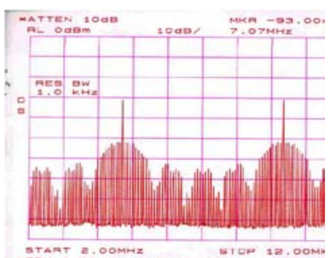


4 inches full open

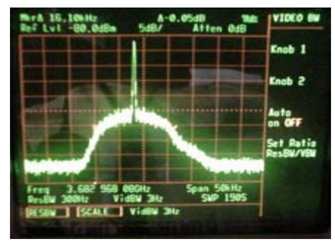
Spectra and Filtering

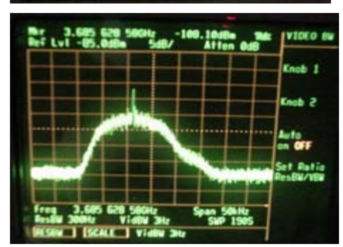
- We have seen Schottky spectra that don't have huge coherent lines (EPAC2002), gold FY02, longitudinal only
- Signal to noise ratio is excellent
- Next step is to build a filter (for momentum cooling)



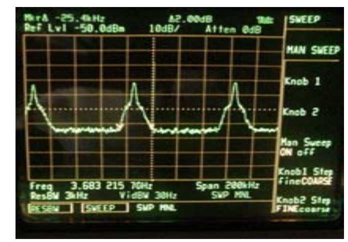


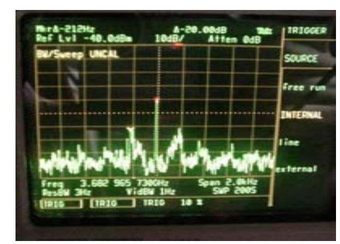
Spectrum at high frequency (top,3.7GHz) and low frequency (bottom,12MHz) show the same bunch frequency lines





Coherent lines are 20 dB above Schottky at bunch frequency, but only 6 dB at revolution frequency harmonics

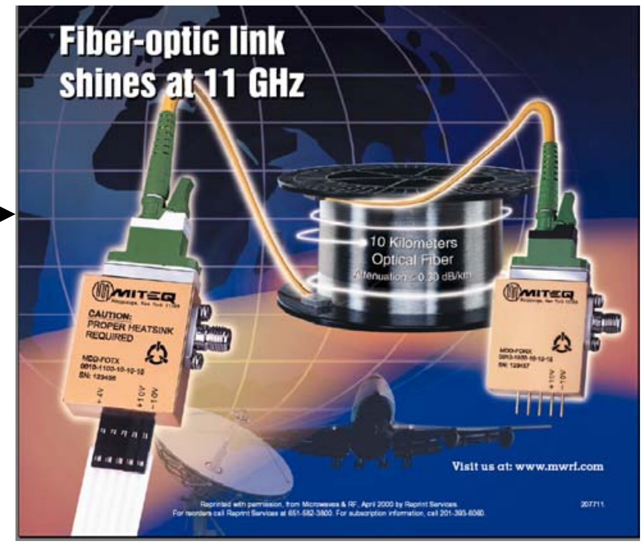




Top is three revolution frequency lines showing that the mixing is not good. Bottom is synchrotron sidebands with beam in full 197 MHz bucket, fs = 214 Hz

Fiber Optic Gizmos

- We need 12.8 microsecond delay with no dispersion at 4 to 8 GHz to make a correlator filter → **BINGO** →
- The filter can do three things
  - Produce the right sign kick for off-momentum particles
  - Kill the coherence spikes in the spectra
  - Provide one-turn delay (maybe we don't have to cut a cord of the ring)
- The noise figure is so good that the filter can be applied just after the preamp (no saturation)



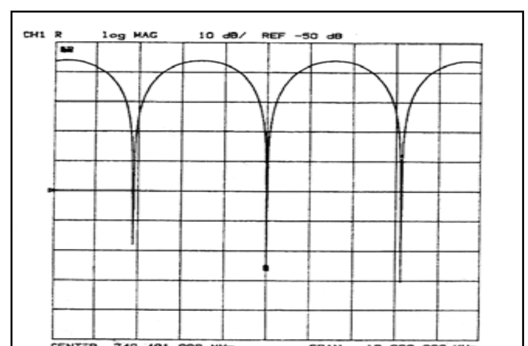
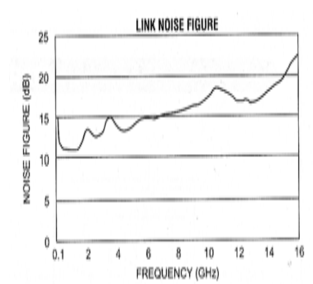


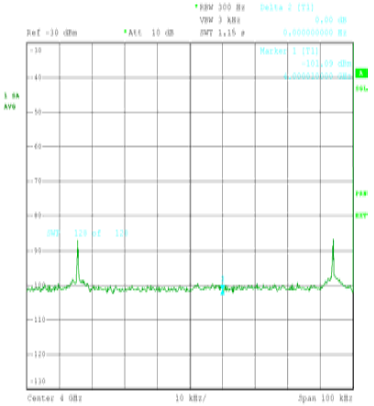
Figure 4. Daresbury SRS correlator 750 MHz notch. The notch depth is 70 dB.



Noise figure of fiber optic link. At Tevatron it was > 40 dB

Power Amplifiers

- This component will dominate the cost of the system
- TWT (Traveling Wave Tube) amplifiers are available commercially
  - At 100$/Watt ⇒1 M$/ring
  - The main goal of the next phase of studies is to nail down this requirement
  - [Aside: 2 M$ for 100 % increase in luminosity would not be bad economics]
- We need to buy a TWT for the Beam Transfer Function measurements
- We will measure HFT (hardware) before beam is on
  - Learn about microwave propagation in the beam pipe
  - Can be done narrowband
  - Borrow/rent power amp
- There may be more clever solutions for power amps(below)



Beam in Blue only

Challenges

- Higher impedance kicker
  - FNAL recently upgraded the stochastic cooling system for the pbar accumulator
  - Using slotted waveguide slow-wave kickers
  - We have more available insertion length (2x kickers⇒1/2 power)
- Pulse compressor (Fritz Caspers)
  - A waveguide with large dispersion (different frequencies travel at different speeds)
  - Stretch the 5 ns pulse before the TWT to 100 ns, then compress at high power before the kicker
  - Reducing the peak power by 20 reduce the cost by almost at much
  - Never been done!
- Use very many narrowband channels (Boussard SPS idea)
  - When the beam is bunched most of the spectrum is redundant information
  - 5ns bunches ⇒ kick can be constructed from Fourier components at 200 MHz
  - 4 GHz/200 MHz = 20 terms in the series
  - Make 20 narrowband, high impedance kickers

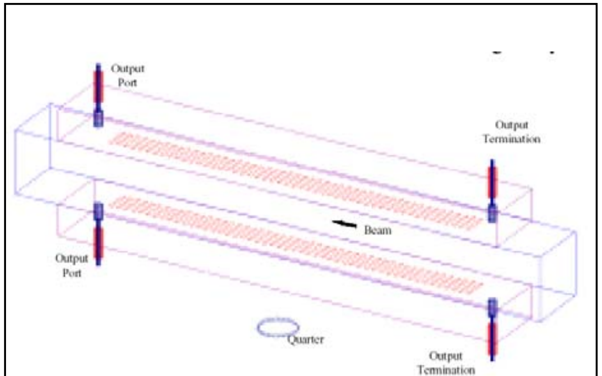


Figure 1: Conceptual drawing of a slow wave pickup

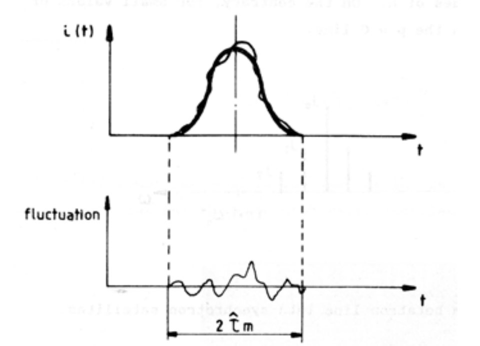


Fig. 7 Time domain of representation o

Future(istic) Directions

- Transverse cooling
  - More ambitious because real cooling (not refrigeration) is called for
  - Must first understand emittance growth (beyond IBS)
- Higher frequency
  - 16 GHz is imaginable
  - Bad mixing becomes significant problem
  - One-turn delay is not possible
- Using the electron beam for a kicker
  - Very far out…
  - A way to go beyond electron cooling
  - The electron beam could give coupling (via the friction force) a very high frequency
  - Needs very high frequency pickup (maybe synchrotron light)