

Summary of session I: Injection, Instabilities and Feedback

Y. Y. Lee (BNL): Injection

E. Shaposhnikova (CERN): Instabilities and Feedback

Invited talks

1. **T. Linnear (CERN): Capture losses caused by intensity effects in the CERN SPS**
2. **V. Lebedev (FNAL): Collective instabilities in the Tevatron complex**
3. **M. Blaskiewicz/W. Fischer (BNL): Coherent effects in RHIC**
4. **Y. Kot (DESY): HERA-p instabilities and cures**
5. **V. Ziemann (TSL Uppsala): Feedback system to control self-bunching in storage rings**
6. **O. Boine-Frankenheim (GSI): Stability of intense bunches for different rf wave forms**

Contributed talks

1. **K.Y. Ng (FNAL):** Resistive-wall instability observed at the Fermilab Recycler Ring
2. **H. Burkhardt (CERN):** Single bunch transverse intensity limitations in the SPS
3. **R.W. Hasse et al. (GSI):** Longitudinal impedance and shielding effectiveness of a thin resistive beam pipe for arbitrary energy and frequency
4. **J. MacLachlan (FNAL):** Charge-dependent increase in coherence of synchrotron oscillation at injection
5. **E. Metral (CERN):** Transverse mode-coupling instability in the CERN Super Proton Synchrotron
6. **M. Kirk (GSI):** Beam loss and longitudinal emittance growth in SIS
7. **A. Lehrach (FZJ):** SIMBAD studies of the effect of impedances on the HESR

Subjects

(I) Coherent effects leading to

- undamped bunch oscillations (M. Blaskiewicz/W. Fischer, O. Boine-Frankenheim, J. MacLachlan)
- beam loss (T. Linnecar, M. Kirk)

(II) Instabilities:

- head-tail (V. Lebedev, M. Blaskiewicz/W. Fischer),
- TMCI (E. Metral, H. Burkhardt)
- resistive wall (V. Lebedev, Y. Ng)
- longitudinal coupled-bunch (Y. Kot)

(III) Cures:

- Impedance studies (R. W. Hasse, A. Lehrach)
- High-harmonic RF system (O. Boine-Frankenheim)
- Feedback (V. Lebedev, V. Ziemann)

Coherent effects (1/3)

Undamped longitudinal bunch shape oscillations observed in the past and now in RHIC, Fermilab Booster, Tevatron, SIS, SPS

Potential well distortion: space charge has **defocusing effect** below transition and inductive wall - above transition.

- RHIC (M. Blaskiewicz/W. Fischer): inductive wall impedance for $\gamma > \gamma_t$ has **focusing effect** in co-rotating frame in phase space - stable hotspots are possible! Explained analytically and in simulations by nonlinear effect - hotspot is contained in its own bucket. Two hotspots are also possible \rightarrow undamped quadrupole oscillations.
 - ⊖ Negative effect for stochastic cooling.

Coherent effects (2/3)

- FMI: Space charge for $\gamma < \gamma_t$ has **focusing effect** and preserves initial bunch injected out of center during hundreds of ms. Long-lived dipole oscillations in simulations. (J. Maclahlan).
 - ⊕ Useful for damping of injection oscillations!
- Condition that coherent dipole frequency is out of incoherent band (loss of Landau damping) agrees well with the threshold for persistent dipole oscillations for SIS (O. Boine-Frankenheim). Similar explanation for dancing bunches in Tevatron (R. Moore et al, Pac'03). Can be damped by longitudinal damper.
Are they the same phenomena? Intensity threshold for hotspots?

Coherent effects (3/3)

Beam loss studies

- **CERN SPS (T. Linnecar):** After significant impedance reduction, with feedback, feedforward and longitudinal damping systems in operation - capture losses of LHC beam for nominal were about 15%. Injection: long bunches in reduced buckets due to energy loss in resistive impedance (asymmetrical motion of lost particles and accelerating bucket are observed). Continuous loss on the 26 GeV flat bottom (10 s). Improvement for larger bunch spacing (e-cloud?) and new working point (space charge?) \rightarrow 7%. During acceleration beam is unstable and cured by controlled emittance blow-up and 4-th harmonic RF system.
- **GSI SIS (M. Kirk):** Studies of capture beam loss (energy mismatch, RF phasing...) Longitudinal emittance growth $\sim 20\%$ could be due to nonadiabaticity. Slow loss after beginning of acceleration. 270% momentum increase with RF off (measured from Schottky spectrum) suggest longitudinal instability.

In both cases transverse resonances are suspected for slow loss!

Instabilities (1/3)

Transverse single bunch instability:

Observed in Tevatron, RHIC, SPS, PS

- Tevatron Complex (**V. Lebedev**): From 6 rings of complex only Debuncher has no problems with beam stability. Suppression of instabilities is an important part of luminosity growth. Weak head-tail in Tevatron is cured by high chromaticity, also reducing beam lifetime. The impedance of 2 laminated Lambertson magnets was identified as a main source of this instability. One magnet is removed and one shielded.
- RHIC (**M. Blaskiewicz/W. Fischer**): Observed at transition crossing when chromaticity is changing sign. Missing impedance for explanation. Worse with space charge.

TMCI was also observed in CERN PS at transition (**E. Metral et al.**)

Instabilities (2/3)

- TMCI or strong head-tail in the SPS (E. Metral): The first time for protons away from transition? Was many times predicted in the SPS (MOSES, coasting beam approximation), but never seen before impedance reduction. Probably because microwave instability was always first. Comparison of MOSES (Y. Chin), Head Tail (G. Rumolo) codes for different parameters. → Good agreement for short bunches. Simulations: space charge significantly increases the threshold for flat chamber (SPS).
- Transverse mode shift measurements (H. Burkhardt): follow-up of transverse impedance reduction and increase (5 extraction kickers were reinstalled in 2003 with RF-bypass). Possible intensity limitation for LHC beam with 4 more magnets. Flat chamber: in horizontal plane small positive shift is only due to resistive wall impedance. Measurements of growth rates as function of chromaticity to improve impedance model. High-order modes should confirm mode-coupling.

Instabilities (3/3)

- **Resistive wall instability in the Fermilab Recycler** was studied in detail (**V. Lebedev**). Maximum amplitude is achieved at 2/3 of bunch length ($6 \mu\text{s}$). Good agreement of calculations with observations. To suppress this instability two-band damper is planned (10 kHz-10 MHz and 10 MHz-200 MHz).
- **Long bunch in barrier bucket** \rightarrow coasting theory (**K. Y. Ng**). Different behaviour of p and pbars can be explained by the difference in transverse size of the beam if space charge suppresses Landau damping.
- **Longitudinal coupled bunch instabilities** in HERA-p (**Y. Kot**). “Elmarmeter” (designed by Elmar Vogel, now at CERN) was used to measure different beam modes.

Cures (1/3)

Impedance studies

Shielding effectiveness - important subject.

- The solutions for longitudinal impedance were found ([R. W. Hasse et al.](#)) for resistive beam pipe of arbitrary thickness. Leontovich boundary condition is an approximation and its applicability for all cases under consideration should be carefully investigated.
- Preparation of tools (SIMBAD) for future impedance studies for HESR (FAIR) ([A. Lehrach](#)).

Cures (2/3)

Double (low) harmonic RF system as upgrade for SIS to increase bucket for fast acceleration and lower bunch peak current → bunch-lengthening mode (BLM) (O. Boine-Frankenheim)

Good agreement between theory and simulation for the loss of Landau damping (dipole mode) due to space charge both for single and double RF systems.

- Observed persistent dipole oscillations could be only worst in the presence of space charge below transition → Phase loop?
Inductive inserts?
- Problem of long bunches in BLM in region with $\frac{d\omega(J)}{dJ} = 0$ - not seen in simulations. However created problem for low-level beam control in CERN Booster. Large beam response was also measured in the SPS.
- Possible problems with acceleration in BL mode (SPS, HERA) due to very narrow region for phase shift → bunch shortening mode is used.

Cures (3/3)

Active damping (feedback/feedforward)

Tevatron (**V. Lebedev**): Transverse feedback is doing more than it was expected due to nonlinearity of applied kick (also shifted in phase to contain both odd and even harmonics). $\rightarrow \xi$ is reduced from 6 to 4. Works for long bunches and bunch by bunch feedback. Unfortunately does not work for all dampers (e.g. SPS).

V. Ziemann: - interesting proposal for **coasting** beam feedback to cure instability due to some (unknown) impedance in the presence of space charge. Based on analogy between energy loss and finite-impulse response filter, where input signal is an earlier charge density and wake function - filter coefficients. Simulations showed that accurate knowledge of the wake-function is required together with well adjusted gain \rightarrow feedforward system!

Discussed solution: to use direct measurements of energy deviation (e. g. radial position/Schottky, ...) - stochastic cooling at low frequency?