REPORT FROM THE TWO-STREAM INSTABILITIES WORKSHOP

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Abstract

The Second International Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings was held on September 11-14, 2001 at KEK in Tsukuba, Japan.[1] This is a report from that conference.

1 INTRODUCTION

The Second International Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings was held on September 11-14, 2001 at KEK in Tsukuba, Japan. Despite the tragic news that arrived from the US on the first day, a very productive series of presentations and conversations were held. The topics of the workshop were divided into four sessions: Electron Cloud Experiments, Electron Cloud Theory and Simulation, Measurement and Diagnostics, and Ion and Dust Effects. All sessions were held plenary style, and included discussions of secondary electron yield, and simulation codes and possible cures. This report will give a brief synopsis of the talks presented.

2 ELECTRON CLOUD EXPERIMENTS

2.1 Proton Machines

Results of experiments at two proton machines were reported. The first talk was by R. Macek on electron cloud experiments performed at the Los Alamos PSR.[2] Observations were made using three diagnostic techniques: biased collection plates inside magnets, a retarding field analyzer (RFA – discussed later by K. Harkay), which gives information about the yield and spectrum of electrons striking the wall, and an electron sweep detector, which measures the electrons in the volume of the beampipe after the passage of a proton bunch. Two populations of electrons are observed. One is a pulse of "prompt" electrons at the bunch tail, which suggests a "trailing edge multipactor," and scales with current as I^7. The second population is the swept electrons sampled after the bunch tail, which scale with I, decay at a time constant of ≈ 170 ns, and implies a high secondary yield (0.5) for $2-5$ eV electrons. Multi-turn accumulation is seen for the swept electrons; neutralization of $1-1.5\%$ is seen after a 100 ns gap. One possible countermeasure is the use of solenoids – the use of a 20 Gauss solenoid reduces wall electrons (the RFA signal) by a factor of 20. A TiN coating for the beampipe is also under consideration.

The second talk was given by K. Cornelius on measurements made at the CERN SPS.[3] The primary diagnostic technique was the use of a strip electrode mounted behind holes in the beam pipe, with additional information from charge-up seen on BPM pickups and vacuum levels. Electron clouds are observed to be created in dipole magnets, shaped like a vertical ribbon. Spectral analysis reveals a fast-growing coupled-bunch instability, with a growth rate of 50 turns, independent of intensity. The instability is of low order, and is handled by feedback. A higher-order head-tail single-bunch instability is also observed in the vertical plane, with an intensity-dependent growth rate (500 turns at threshold intensity, 100 turns at 2× threshold).

2.2 Electron/Positron Machines

Reports were delivered from three electron/positron machines: the electron-positron ring at BEPC and the two positron rings at PEP-II and KEKB. From BEPC, Q. Qin reported on observations using a photo-electron detector consisting of a pickup plate behind slots in the beam pipe, with a variable-voltage grid between the slots and the plate.[4] The detector was placed just downstream (from the positron beam's point of view) of a bend magnet. Initial observations showed that the p.e. signal was 6 times stronger with a positron beam in the ring than with an electron beam, probably due to either the location relative to the bend, or possibly different deflection characteristics. Detailed observations carried out with the positron beam showed that the signal is proportional to bunch current, with no sign of beam-induced amplification (multipacting) when the bunch spacing is varied. A vertical coupled-bunch instability is also observed with a beam-current threshold of 9.8 mA. A 20-Gauss solenoid field was found to be weakly effective in clearing the photoelectrons. Simulations showed agreement with the observed current dependence, and no dependence on assumed p.e. reflectivity.

R. Holtzapple reported on observations made at the PEP-II Low Energy Ring (LER) via gated camera for bunch-by-bunch beam size and SR interferometer for average beam size.[5] Both x- and y-axis beam blowup are observed, dependent on the number of bunches, bunch spacing, and presence of gaps in the train. The source the presumed responsible electron cloud is believed to be multipacting electrons. 30-Gauss solenoids wrapped around the beam pipe reduce the beam size and growth rates. At low beam current a slow, mild growth is observed along the bunch train (a few percent over 120 bunches), while at high current the beam size grows rapidly in the first 10 bunches (8.4 ns spacing between bunches) and then saturates for the rest of the train. Mini-gaps and bunch-current ramps have been found to reduce the saturated beam size and overall average beam size.

At the KEKB LER H. Fukuma reported measurements made via gated camera, streak camera and gated tune meters.[6] At KEKB, only vertical beam-size blow-up has been noted. It is a single-beam, multi-bunch phenomenon, independent of betatron tunes, with the threshold determined by the charge density along the train. As at PEP-II, the vertical size increases at the head of the train, saturating by around the 20th bunch at 8 ns spacing. In the case of two trains, the size blow-up of the second train reaches saturation much quicker than that of the first train; a large gap (240 buckets) is needed to clear electrons after the first train. Increasing chromaticity has been seen to help the blow-up to some extent. The data seem to agree with the single-bunch head-tail instability model of Zimmermann and Ohmi. 30-45 Gauss solenoids around the beam pipe increase the blow-up threshold current, reduce the magnitude of the blow-up, and increase the luminosity.

S.S. Win presented observations made using the bunch oscillation recorder, a bunch-by-bunch, turn-by-turn beam position monitor that is part of the feedback system.[7] The horizontal and vertical mode spectra change when the solenoid currents are turned on and off. The growth rates increase linearly with beam current, and improve 35% with the solenoids on. Horizontal and vertical tune shifts increase along the train and saturate at some point. The solenoids decrease the tune shift. The vertical shift is greater than the horizontal shift when the solenoids are on, and is otherwise equal. Synchrotron sidebands suggest a head-tail instability, and require further study.

T. Ieiri reported on the gated tune measurements at the KEKB LER. Similarly to the vertical beam size, the bunch-by-bunch horizontal and vertical tunes increase along the train and then saturate.[8] The extent of the tune shift agrees with the Zimmermann-Ohmi model. With the solenoids off the horizontal and vertical tune shifts are equal. When the solenoids are on the shifts are reduced, but the horizontal shift is reduced more than the vertical shift. The bunch oscillation recorder and gated tune meter measurements are in agreement.

3 ELECTRON CLOUD THEORY AND SIMULATION

F. Zimmermann discussed simulations of electron-cloud build-up in the CERN PS, SPS, LHC, and the KEKB LER..[9] The simulation code uses sliced bunches and macro-particle electrons and secondary electrons from the wall. Electrons are accelerated in the gap between beam bunches and propagate taking account of any magnetic field present with kicks from space charge and electron image charges. Far from the beam bunch is the "kick" region, while near the bunch is the "autonomous" (oscillatory) region. Hilleret's double-peaked distribution is used for secondary electrons; various models are tried for the low-energy "true" secondaries, in particular for the behavior near zero. Results of simulation are roughly consistent with observations at the SPS, PS and at KEKB concerning build-up time, central density and population of electrons near the wall. Single-bunch instability shows agreement with Ohmi's code. Space-charge strongly modifies the the effect of the electron cloud. Dipole magnetic fields lead to striking vertical stripe cloud distributions. Finally, he concludes that electron clouds could be the most significant problem for the next linear collider.

F. Zimmermann also discussed simulations of the longitudinal wake due to electron clouds at the SPS and KEKB LER.[10] From plasma physics considerations, an enormous effect was feared ($E_z = 100$ kV/m at SPS). Using a 2-D particle-in-cell (PIC) code, a uniform electron cloud in front of a bunch was simulated. The result was that the effect is much smaller than expected: ≤ 10 V/m at SPS, and negligible for KEKB.

V. Danilov discussed 3D simulation code under development for the ORNL SNS ring to model e-p instability as seen at the LANL PSR and the BNL AGS booster.[11] He considers two scenarios for electron cloud accumulation. The first is single-pass accumulation due to multipacting of trailing edge of the proton beam. For electrons near the wall, increasing the longitudinal bunch density leads to energy loss while decreasing density leads to energy gain, which in turn leads to multipacting if the secondary emission coefficient of the wall is high enough; TiN coating is proposed to avoid this. The second scenario is multi-pass accumulation. If 1% of the protons stray into the gap, then the electron cloud density doubles after one turn. Probable accumulation spots are the collimators, stripping foil region and ceramic pieces.

D.V. Pestrikov talked about fast single bunch instabilities in storage rings.[12] Assuming wakes from one bunch decay before the next bunch and that the instability is much faster than synchrotron oscillations, he considers the relative importance in fast single-bunch oscillations of beam breakup and of the conventional self-consistent instability parts. His conclusions are that the behavior shows two timescales. The initial, transient part part is beam break up, sensitive to chromatic betatron frequency spread. The self-consistent spectrum is sensitive to chromatic betatron phase advance, and microwave solutions lead to beam-breakup instability. However, the numerical model is too crude for realistic evaluations of the effect of chromaticity on global stability of the oscillations.

E. Perevedentsev simulated head-tail instabilities caused by photoelectron clouds in the KEKB LER.[13] He models beam-cloud interaction as a beam-beam breakup problem with an oscillating dipole wake function. Non-uniformity of the positron bunch density leads to frequency spread and decoherence of p.e. oscillations. He simulated strong head-tail instability using a linearized Vlasov approach. The effect of transverse feedback is that at zero chromaticity, the feedback only acts on the $l = 0$ mode, while at positive chromaticity higher-order synchrotron-beta modes are excited. The instability threshold increases with wake frequency, bucket spacing and bunch length. At the KEKB LER, feedback damping of the $l = 0$ mode leads to excitation of higher order modes, which is then suppressed with positive chromaticity. But systematic study of the optimal combination of feedback parameters and chromaticity to raise the blow-up threshold has not been done, and is urged. Synchrotron sideband dependence on current and chromaticity should also be studied.

K. Ohmi discussed analytical and numerical simulations on beam-electron cloud interactions.[14] He found that the tune shift of the beam is determined by the shape of the cloud: electrons far from the beam are important. The relative horizontal and vertical tune shifts are determined by the relative horizontal and vertical extents of the cloud. (This has implications for the tune shifts measured and reported by Ieiri[8] and Win[7] at the KEKB LER.) Electrons near the beam (within a few beam sigma) contribute to the wake field. Electrons far from the beam are not moved by the beam force.

H. Qin developed simulation code based on the nonlinear Vlasov-Maxwell equations for efficiency in treatment of space-charge impedance and for handling of damping mechanisms that determine growth rates and thresholds of collective instabilities.[15] Applying the code to the PSR, they find the e-p instability has a dipole mode structure, and the growth rate increases with the proton density and fractional charge neutralization. Stabilization comes from axial momentum spread and space-charge induced tune spread.

M. Pivi made simulations of the LANL PSR focusing on secondary electron yield and energy spectrum.[16] He simulated electron cloud current at the wall with a detailed secondary electron yield model including an electron multiplication mechanism, with a double-peaked secondary electron spectrum. The electron intensity and low energy spectrum agreed with measurements. TiN appears to be effective at the wall. The intensity is surprisingly dependent on the details of the low-energy secondary electron yield.

L. Wang performed simulations of electron clouds in the KEKB LER using a 3D PIC solver which can handle irregular meshes and non-linear fields.[17] The positron bunch is sliced, and the electrons are treated as macroparticles. He used a finite element potential solver, and for comparison tried a Poisson solver with similar results. The results were that addition of a magnetic field reduces the central density of the cloud, but not the average density, as electrons get pushed to the walls. A uniform solenoid field is the most effective field for clearing electrons. In lattice magnets he found that not only dipoles but also the higher order magnets (quadrupoles, sextupoles and up) can be significant sources of trapping during train gaps. Short trains reduce average density in the magnets.

Y. Suetsugu simulated multipacting at the KEKB LER.[18] Observed phenomena are nonlinear pressure rise, strong in straight sections, which varies with fill pattern and is reduced by solenoids. He did a 2-D simulation of gas desorption due to electron multipacting assuming 2-8 eV initial energy of emitted electrons, a cosine law angular distribution and a simplified secondary yield curve. Results were very similar to observation, but with different thresholds. A 10-gauss solenoid makes a big difference, but little additional benefit is found with stronger fields.

4 MEASUREMENT AND DIAGNOSTICS

4.1 Secondary Electron Yield of Copper

N. Hilleret and Y. Suetsugu presented their measurements on the secondary electron yield of copper. Hilleret measured the variation with dose of electron bombardment. The energy distribution is double peaked at 2 eV and 9 eV.[19] He fits this to a 2-component model comprising low-energy secondaries and a “high” energy reflected population. He also found that re-conditioning after air exposure is 10× faster.

Y. Suetsugu made measurements using synchrotron radiation at the KEK Photon Factory with a critical energy of 4.1 keV to measure the p.e. yield and distribution from models of the KEKB LER beampipe with both smooth surface (as currently used) and with an experimental sawtooth inner surface, finding that the sawtooth surface generated a yield less than 6% of that for the smooth surface.[20] He also measured the reduction of PEs at the beam position when magnetic fields are applied. For a solenoid field, uniformity of magnic field is important; a continuous solenoid is better than an alternating field. A 50 Gauss field reduces p.e.s to less than 10% at the beam position.

4.2 Properties of Electron Cloud

K. Harkay discussed instrumentation used measure electron cloud properties at the Advanced Photon Source.[21] The retarding field analyzer (RFA), using an electrode and potential grid behind beam pipe slots, has the advantage of high transmission (80%), but the energy analysis turns out to be somewhat complicated.

A Bessel box analyzer using magnetic fields has the advantage of making direct analysis of the energy spectrum possible, in exchange for a narrow acceptance angle and low transmission. Finally, BPM electrodes which are already in place can be used as well, though biasing changes the collection length and secondary electrons from the surface affect the measure of the true flux.

Y. Ohnishi discussed measurements using a photoelectron detector at the KEKB LER, with slots, grid and plate, similar in design to the RFA.[22] The yield measurement is complicated by the need to consider the acceptance and particularly the effect of solenoid fields on acceptance. The energy spectra of the PEs at the KEKB LER was found to have an excess at 35 eV.

At the SPS, the initial detection of electron clouds was via observation of pressure rises. J.M. Jimenez discussed the strip and triangle electrode detectors mounted behind beampipe wall holes in the dipoles to measure the electron cloud intensity and energy distribution.[23]

5 ION AND DUST EFFECTS

T. Nakamura reported on possible fast-ion instability phenomena at the 8 GeV electron light-source storage SPring-8.[24] After installing 30 meter long straight sectoins, many peaks were seen at lower betatron sidebands on the BPM signals. A vertical beam size increase was seen, which was suppressed by raising the chromaticity to 17, at which point a horizontal beam size increase was observed. Over a period of years, the instability has gradually ameliorated. There seems to be an enhancement of a vertical coupled-bunch instability which was originally caused by resistive wall impedance. The instability gets worse with vacuum pressure and with longer bunch trains, and can be cured by adding a small, 100 ns gap to the fill pattern.

A. Mochihashi showed measurements of the bunch-by-bunch tune at the KEK Photon Factory with a high-speed light shutter (Pockels cell) and edge mask, in order to look for a predicted structure in the beam bunch-by-bunch tune shift due to trapped ion effects.[25]

Q. Qin discussed suspected dust phenomena at the BEPC storage ring. In single electron beam (SR) mode, they sometimes get sudden lifetime drops from 8-10 hours to 2 hours or less in single beam mode, or from 20-25 hour to 5-6 hours or less in multi-bunch mode.[26] These events happen suddenly, are non-reproducible, and never happen in e^+e^- collision mode. The frequency has gotten worse from year to year. Sometimes applying a kick to the beam or varying the rf frequency helps. As experiments, they have found that turning on the distribution ion pumps (DIPs) can trigger the phenomenon, suggesting that the DIPs are spewing magnetic oxide particles. A "duststrahlung" analysis seems consistent with SiO2, based on frequency and critical current. The best solution would be to switch to a positron beam in SR mode, for which they need to improve the injection rate.

M. Tawada discussed a simulation of fast ion effects at the proposed SuperKEKB luminosity upgrade to KEKB.[27] Signatures of fast ion instability are currently seen in the KEKB electron ring, but are so far successfully damped by bunch-by-bunch feedback. The design current for the electron ring would go from 1.1 A to 10 A, and the pressure from 1 nTorr to 2.3 nTorr. In addition, the beam energy would switch from 8 GeV to 3.5 GeV, making the electron ring the Low Energy Ring. Using a 2-D weak-strong code, treating the electron beam as a rigid Gaussian with ion macro particles and one collision point assumed, the growth time would be about 30 turns (0.3 msec) at 1 nTorr and 5 turns (0.05 msec) at 5 nTorr for 4800 bunches. With a feedback damping time of 0.5 msec, the vacuum would need to be improved to less than 0.5 nTorr.

K. Ng presented some measurements on beam-ion instability at the Fermilab linac.[28] The linac beam is H^-, and the residual gas is mostly protons. They also tried adding hydrogen, helium, nitrogen, argon and krypton. The pulse length is 35 μsec, and they take the FFT of the last 20 μsec of a BPM signal. If they are observing fast-ion instability, the resonant frequency should be the ion-in-beam bounce frequency, and be independent of pressure. The results with different gases were mixed on this score, with argon and krypton showing different peaks at different pressures, but no change for helium, nitrogen and hydrogen. However, the frequency is generally the bounce frequency, and the expected fast growth and saturation generally match the expectations from fast-ion instability. They consider that they also need to take into account the beam-in-ion bounce frequency (and pressure dependence), and may need to try the using reduced-mass.

J. Dooling presented some considerations of plasma formation at the IPNS Rapid Cycling Synchrotron, which has 3×10^{12} protons/pulse and a background pressure of 1 μTorr of nitrogen.[29] They expect significant plasmas. With a short neutralization time, a neutral plasma should form quickly, but with a high ratio of peak to average current, non-neutrality should arise along the beam path. Observed tune shift suggests self-focussing. To investigate further, they need new diagnostics, such as a Langmuir probe and interferometer.

6 SUMMARY

The workshop was about 75% concerned with electron cloud issues, 25% ion and dust issues. The main themes that arose were concerns about the understanding of secondary electron yields, including a lengthy discussion of the energy distribution of secondary emitted electrons. Many basic electron cloud mechanisms seem to be agreed on, and the simulations largely agree with observations, but not in all details. Dust issues seem to be less well developed.

More diagnostics are needed to prove that the proposed mechanisms are correct, and more and better counter-measures are very much needed.

Despite the unfortunate timing in relation to world events, the workshop was a very productive one.

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