Minutes of the SPS Studies Working Group (SSWG)

10^{th} meeting 23^{rd} October 2001

Present: H. Burkhardt, R. Cappi, P. Collier, K. Cornelis (chairman), B. Dehning, L. Jensen, D. Manglunki, G. Rumolo, E. Shaposhnikova, R. Tomas, J. Tückmantel, L. Vos, F. Zimmermann (secretary)
Excused: T. Bohl, W. Hofle, T. Linnecar

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1 Observations on Electron Cloud Instability (K. Cornelis)

Analysis of multi-bunch multi-turn BPM data for an LHC batch reveals the nature of the instability in the two transverse planes. This year's observations confirm the conclusions of Chamonix and provide further insight.

In the horizontal plane, the instability is of a coupled-bunch type, which means the motion of subsequent bunches is correlated. Decomposing the bunch motion into multi-bunch modes indicates that only the lowest modes are unstable. Above the multipacting threshold (about 3×10^{10} protons per bunch) the horizontal instability is seen from about the 10th bunch in the train and it starts about 30–50 turns after injection. At twice the bunch population, the horizontal instability still looks about the same.

The instability signal disappears at later times during the store, which is believed to be due to blow up of the bunch volume. The later bunches show two tune lines which are split by about $\Delta Q \approx 0.03$. K. Cornelis discussed an analytical model of the coupled bunch instability, which predicts two tune lines. The distance between these lines is proportional to the coupling, which increases linearly with electron cloud density. Thus estimating the electron density from the measured value of ΔQ, K. Cornelis obtained a number consistent with the density found in simulations. It was mentioned that an SVD analysis of eigenmodes and eigenvectors by G. Arduini agrees with the model calculation, and that this analysis also suggests that the electron cloud long-range wake field extends over about 3 bunches. If the horizontal damper is set up properly and operated at maximum gain, it completely suppresses the horizontal instability. This set up proved more difficult this year, after the increase of the damper bandwidth. In the horizontal plane, it may therefore be advantageous to operate the damper with smaller bandwidth and higher gain. There are some trade offs in the damper operation between the requirements for damping injection oscillations and for suppressing the electron-cloud instability.

In the vertical plane, at the onset of multipacting the instability is much weaker than in the horizontal plane. It is visible after about 400 turns. For twice the bunch intensity (6×10^{10}) the instability growth rate becomes comparable to the horizontal growth rate, $\tau \approx 40$ turns, however. Thus, unlike for the horizontal plane, the vertical instability depends strongly on the bunch intensity. R. Cappi suggested that the instability characteristics can be affected by coupling. In the vertical plane, without feedback all multi-bunch modes are unstable, and only the lower-frequency modes can be stabilized by the damper. All observations support the interpretation of a single-bunch instability. At higher intensity, different head-tail modes are visible in the vertical tune spectrum. Raising the chromaticity sufficiently far that the chromatic tune spread overlaps the distict modes suppresses the vertical instability. A detailed analysis of the mode spectrum shows that the damper is effective up to about 15 MHz. E. Shaposhnikova asked for the evidence that the instability is really a single-bunch instability due to the electron cloud and not a conventional coupled-bunch instability. In response, K. Cornelis mentioned the broad mode spectrum, the fact that the most intense bunches are the first which become unstable, a 600–700 MHz signal detected on a wide-band pick up, the observation that the characteristic length of the wake inferred from the head-tail monitor is about 1/3 of the bunch length, as expected from the electron motion, and the strongly nonlinear dependence of the growth rate on bunch current.

Recent observations show a difference in the electron-cloud signal and beam loss of the FT physics beam whether or not the LHC beam is present during the MD cycle. This possibly indicates that electrons survive in the beam pipe over a time scale of seconds.

2 Impedance MDs (H. Burkhardt)

On 01/10, 02,10, and 18/10 MDs were performed with the single-bunch MESPS beam. One aim was to confirm the reduction in the transverse impedance, by measuring coherent tune shifts and head-tail growth rates for a longer bunch length and lower rf voltage than previously. This was a compromise, since a different beam energy was not available.

Data were taken up to a maximum single-bunch intensity of 1.2×10^{11} to be sensitive to space-charge effects. The highest bunch population corresponded to an incoherent space charge tune shift of about 0.01. The beam was still well behaved, with undamped oscillations after a kick and good lifetime. No enhanced sensitivity to the working point was seen.

Tune measurements were also conducted for nonzero chromaticity $\xi \approx 0.1$ in order to make the synchrotron sidebands visible. At $\xi \approx +0.15$, bunch oscillations were recorded as a function of intensity for three different rf voltages. The measured growth and damping rates vary linear with chromaticity ξ over a large range of values, but appear to bend over at larger negative chromaticities, which roughyl correspond to the estimated resonator frequency of 1.3 GHz.

In the horizontal plane, two peaks were seen in the tune spectrum. One peak may be interpreted as a synchotron sideband. H. Burkhardt showed that the variation of the measured distance between the two peaks as a function of rf voltage changes at higher bunch intensities. If one identifies the distance between the tune peaks with the synchrotron tune, the measured dependence on intensity could be used to calculate the longitudinal loss factor. K. Cornelis pointed out that the distance between the peaks might also shift due to an intensity dependence of the $l = 1$ mode frequency. Measurements of bunch length vs. rf voltage, also performed in these MDs, contain information about both energy loss and potential-well distortion.

In the vertical plane, many more modes are seen, extending at least from $l = -1$ to $l = +2$. Sometimes as many as 10 modes are present in the spectrum. A sliding window analysis is applied to infer the decay time of each individual mode. For positive chromaticity, the $l = 0$ mode shows the fastest decay. For low intensity, two peaks are seen in the vertical spectrum, which are separated by much less than the synchrotron tune. The tune peaks separate for increasing current. The origin of this tune split is yet unknown. Possible explanations include radial modes and the 0' (zero-prime) mode also seen in LEP, which is located at the center frequency between the $l = -1$ and $l = +1$ modes. It was emphasized by various people that care must be taken in interpreting all these observations. E. Shaposhnikova mentioned that the bunch profile should always be monitored, and that the bunch distribution changes with current.

3 Impedance and Space-Charge Simulations (G. Rumolo)

G. Rumolo's code was originally developed for simulating the electron-cloud single-bunch instability, but it can also be employed to study conventional instabilities due to a broadband impedance and the effect of space charge.

Simulated centroid motion in response to a kick closely resembles the observations both for positive and negative chromaticity. G. Rumolo compared the simulated instability growth rate as a function of negative chromaticity with the theoretical prediction for a Gaussian distribution and obtained a good agreement. The simulation included the transverse space charge force, while the theoretical formula does not. This suggests that space charge does not much affect the growth rates.

H. Burkhardt and G. Rumolo pointed out that the analysis of the simulation data was made employing exactly the same programmes as are used to process the real measurements. This comparison, therefore, provides an independent verification of the processing procedure.

Simulations of $l = 0$ mode oscillations including only the (linear) space-charge force, which is modelled in two different ways (additional rotation, and many kicks, respectively), do not show any sign of decoherence or damping.

4 Next Meeting

The next meeting of the SPS SWG is tentatively scheduled for Tuesday, 6th November, at 09:15, in Room 865-1D17. The agenda will be posted on the web page of the working group http://cern.ch/sl-mgt-sps-swg, and an invitation will be sent by email.

F. Zimmermann, 23rd October 2001