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LONGITUDINAL STABILITY OF ELECTRON BUNCHES INJECTED INTO THE SPS

E.J.N. Wilson and B. Zotter

1. Introduction

A recent LEP Note by Baconnier and Madsen[1)] points out, among other things:

(a) That the fully damped electron bunch from the PS will be unstable when injected into the SPS because of microwave instability.

(b) That the bunch must therefore be inflated before transfer to make it stable and, though a number of mechanisms for this are being considered, no completely satisfactory method has yet been found.

(c) That if the particles with an energy increment of 3 σ_E are to remain stable from a single particle point of view, σ_E/E must be less than 1.7×10^{-3}.

(d) This places a limit on how much the bunch can be inflated and hence on the maximum intensity per bunch that can be transferred. The intensity limit is 1.8×10^{11} compared with the design aim of 2.8×10^{11} in four bunches.

In the following note we describe BBI calculations which confirm the stability limits quoted in LEP Note 325, and in addition give the growth rate of the multibunch longitudinal instability. However, we show that by relaxing somewhat the condition that σ_e/E is less than 1.7×10^{-3}, a liberty which we feel is justified in the light of improvements in chromatic correction of the SPS lattice, one obtains stability at the intensity and beam parameters assumed in the Pink Book Addendum[2)3)].

Finally, we restate the preferred parameters of a stable bunch with the suggestion that - if a mechanism to preinflate the bunch is to be found - one should aim at injection parameters which ensure the full design intensity.

2. Multibunch Instabilities

The Table gives the bunch parameters of a beam which is just stable against microwave instability and which is subject to potential well bunch lengthening. BBI scans the standing wave cavity frequency to find the condition for which the most dangerous multibunch mode is minimum. This happens when the cavity is tuned about 1.2 kHz below the r.f. frequency in accordance with Robinson's criterion. The full complement of 64 standing wave cavities are assumed to be installed and the impedance of the travelling wave structures is included in the model. The unstable mode numbers are m = 1, n = 3, i.e. the dipole mode with $3\pi/2$ phase shift from bunch to bunch. The rise time in column 6 is comparable or longer than the expected acceleration cycle.

3. Results of BBI Calculations

The first line of Table 1 confirms one of the stability thresholds given in LEP Note 325. (It is to be found on the eighth line of Table 2 of that note). This is not surprising since both calculations use the same theory. Note that the total beam is 1.8×10^{11} rather than the 2.8×10^{11} quoted in the Pink Addendum.

Table 1

Bunches which are stable against Microwave Instability

($E = 3.5$ GeV, 4 bunches, $Z/n = 15\ \Omega$)

V_{rf} [MV]	Total beam	σ_e/E [10^{-3}]	σ_s [cm]	Q_s	$1/\tau$ [s]
2.5	1.8×10^{11}	1.46	15.0	0.027	0.55
8.0	1.8×10^{11}	2.00	10.4	0.039	0.96
8.0	1.3×10^{11}	1.66	8.6	0.039	0.73
8.0	2.8×10^{11}	2.19	10.6	0.042	1.40
12.0	2.8×10^{11}	2.38	9.1	0.053	1.20

The first modifications to these bunch parameters which we suggest is to use a higher r.f. voltage. Not only does this slightly improve stability ($N \propto V^{1/4}$) but it raises Q_s to a value which can be sustained throughout the acceleration cycle, a condition which PETRA found to be more important than any other in running the machine. In the second line we see how a rise to 8 MV has increased Q_s and shortened the bunch. Naturally σ_e/E is now larger than the limit imposed in LEP Note 325.

The third line uses an intensity corresponding to the "double interleaved" mode. Both Q_s and σ_e/E are satisfactory.

The fourth line gives parameters of a stable bunch of the design intensity, and we see by comparison with the third line that only a small increase in bunch length and energy spread is necessary to double the intensity.

The fifth line is the set of parameters we recommend for ongoing study. The voltage has been raised somewhat since, although 8 kV gives a single particle Q_s close to the nominal 0.05, it is depressed by collective effects. With 12 kV Q_s is close to the nominal value at high energy.

4. The Problem of Energy Spread

The periphery of the bunch described in the last line will contain partifles whose energy increment is $\Delta E/E = \pm 7.4\ ^\circ/_{\circ\circ}$. These particles will be at most 30 mm from the axis of the SPS, less than half the geometric aperture. Early calculations of chromaticity at 3.5 GeV showed that with only two families of sextupoles the increment in Q due to the second order chromaticity at this low energy would be > 0.15, a large value when one is trying to steer between synchro-betatron resonances.

However, the new families of sextupoles recently installed improve the second order chromaticity coefficient by an order of magnitude and we are no longer frightened by a $\Delta E/E$ of $7.4\ ^\circ/_{\circ\circ}$ [4].

5. Discussion

Ideally the SPS beam should have the following parameters for injection at 3.5 GeV:

Intensity (4 bunches)	2.8×10^{11}
Energy	3.5 GeV
RF voltage	12 MV
Ψ_s	170°
σ_e/E	2.4×10^{-3}
σ_s	0.09 m
Q_s	0.05

It will then be stable longitudinally except for a multibunch instability with a rise time of 0.8 seconds.

It should, however, be said that PETRA experience with transverse instability and synchro-betatron resonances is a strong incentive to raise the injection energy, which is only half that of PETRA. These effects have not been treated in this study.

It should also be noted that lowering Q and the transition energy of the SPS (to, say, 14) helps the stability of the injected beam. The stable energy spread is halved. It remains to be seen if sextupole patterns can be found to linearise the Q variation under these conditions.

References

1. Y. Baconnier and J.H.B. Madsen, "An Intensity Limitation in the LEP Injector, LEP Note 325.
2. The Use of the SPS as a LEP Injector, CERN/ISR-LEP/79-33/Add.
3. B. Chen, S. Chen, E.J.N. Wilson, B. Zotter, IEEE Trans. Nuc. Sci. Vol. NS-28, No. 3, p. 2537 (1981).
4. P. Faugeras, Study of 3.5 GeV Dynamics (to be published).