EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — SL DIVISION

CERN SL-98-024 RF

Measurement of the Effect on Single Bunch Stability of Changing Transition Energy in the CERN SPS

T. Bohl, M. Lamont, T. Linnecar, W. Scandale, E. Shaposhnikova

Abstract

The SPS is the final accelerator in the chain which will be used to fill the Large Hadron Collider (LHC), at present under construction at CERN. The most critical limitation for single bunch intensity in the SPS comes from the longitudinal microwave instability. One of the ways to raise the instability threshold is to decrease the transition energy which can be obtained by perturbing the dispersion function. In order to test expectations an experiment was performed in the SPS using the existing lattice. By adjusting the betatron tune at 26 GeV to be close to a multiple of the machine super period, a situation not acceptable for regular operation, the transition energy was reduced from 22 to 19 GeV. The results of this change on the beam were measured directly from the bunch spectrum.

Presented at EPAC-98, 6th European Particle Accelerator Conference
Stockholm
22-26 June 1998

Geneva, Switzerland
June, 1998

Measurement of the Effect on Single Bunch Stability of Changing Transition Energy in the CERN SPS

T.Bohl, M.Lamont,T.Linnecar, W.Scandale E.Shaposhnikova, CERN

Abstract

The SPS is the final accelerator in the chain which will be used to fill the Large Hadron Collider (LHC), at present under construction at CERN. The most critical limitation for single bunch intensity in the SPS comes from the longitudinal microwave instability. One of the ways to raise the instability threshold is to decrease the transition energy which can be obtained by perturbing the dispersion function. In order to test expectations an experiment was performed in the SPS using the existing lattice. By adjusting the betatron tune at 26 GeV to be close to a multiple of the machine super period, a situation not acceptable for regular operation, the transition energy was reduced from 22 to 19 GeV. The results of this change on the beam were measured directly from the bunch spectrum.

1 INTRODUCTION

The longitudinal emittance budget for the LHC beams in the SPS is very tight, ≥ 0.4 eVs at injection and ≤ 0.7 eVs at extraction. One possible cause of emittance growth for single bunches comes at injection into the SPS from the single bunch microwave instability mainly caused by the impedance of about 800 intermagnet pumping ports, cavity like elements with low quality factor Q and large R/Q where R is the shunt impedance.

One way of raising the threshold of this instability is to increase the slip factor $\eta = 1/\gamma_{tr}^2 - 1/\gamma^2$ of the machine. This can be achieved in a controlled way by placing two new families of quadrupoles in the machine. However in order to make tests without installing extra quadrupoles, large changes in η can be produced in the SPS for energies close to transition energy by operating at tune values close to a multiple of the super-periodicity of six. In this case resonant behaviour of the dispersion in the SPS arcs due to the uneven distribution of the machine dipoles causes the γ_{tr} to change significantly. This technique while allowing tests at different η's to be made without changes to the hardware in the machine, implies very careful setting-up of the machine especially concerning the orbit and transfer line matching. This procedure has been described in more detail in [1].

Previous studies [2] have shown how the machine impedances can be measured from the spectrum of long single bunches injected above threshold into the machine. Here this measurement was used to give an estimation of the influence of changes in η on the bunch stability.

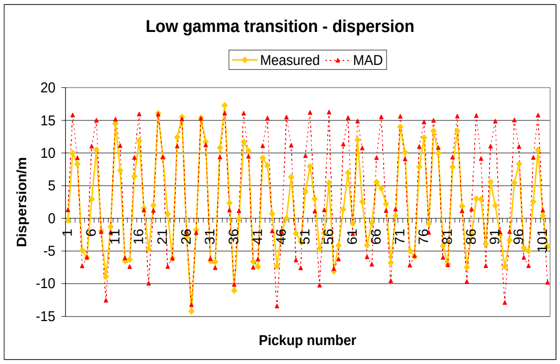


Figure 1: Measured and calculated (MAD) dispersion for low γ_{tr}

2 ESTABLISHING THE EXPERIMENTAL CYCLES

The measurements described here were performed on the 26 GeV subcycle of the SPS supercycle. One optics of this subcycle had the usual integer tune of 26, (normal γ_{tr}), and the new one with the larger η, (low γ_{tr}), had integer tunes of 24 in both planes.

The relevant accelerator and beam parameters during the experiment are given in Table 1. The values for γ_{tr} are those obtained from the MAD programme. They indicate that these operating points can give a change of a factor $\sim$2.5 in η. The dispersion around the machine for the low γ_{tr} case is shown in Fig.1. The dispersion for the normal γ_{tr} cycle is always positive, for the low γ_{tr} cycle the dispersion becomes negative at certain positions. Fig.1 also shows the measured dispersion obtained by taking the difference between two orbits at different energies.

For the low γ_{tr} cycle re-matching of the injection line to the new injection conditions, chromaticity adjustment and careful closed orbit correction were all necessary before a correctly circulating beam without loss could be established. Once the setting-up had been done it was possible to switch between the two cycles fairly rapidly ensuring that the injected beam parameters remained constant.

3 MEASUREMENT OF η

For the low γ_{tr} case, where the dispersion changes rapidly as a function of tune value, tune knowledge may not be sufficiently precise to calculate η with MAD.

Debunching can also give information about the η. For an intense beam the debunching depends on the machine

Cycle	normal γ_{tr}	low γ_{tr}
Q_h	26.62	24.29
Q_v	26.58	24.32
γ_{tr}	23.23	19.59
E_s (GeV)	26	26
η	$0.551\ 10^{-3}$	$1.3\ 10^{-3}$
$\tau(0)$ (ns)	25	25
ϵ (eVs)	0.37	0.37
N	1.5×10^{10}	1.5×10^{10}

Table 1: Accelerator and injected beam parameters

and bunch parameters and on intensity via the machine impedance. For an inductive impedance, intensity effects can be easily taken into account [2]. However, interpretation of the data can be affected by an increase in the momentum spread due to instabilities. We have used the available data, with the approach developed in [3], to estimate the change in η.

The parameters of interest are

$$\Omega = \frac{2\eta}{\tau(0)}\frac{\Delta p}{p}, \qquad \Omega_\epsilon = \left(\frac{6\mathrm{N}e^2|\eta|}{\pi E_s \tau^3(0)}\ \frac{|\mathrm{ImZ}|}{\mathrm{n}}\right)^{1/2}. \quad (1)$$

The first defines the debunching at zero intensity and the second introduces the intensity effects for a parabolic bunch. $\tau(0)$ is the initial bunch length, $|\mathrm{ImZ}|/\mathrm{n}$ is the low frequency machine impedance and $\Delta p/p$ is the relative momentum spread.

These parameters, calculated for the theoretical values of the two cycles and the bunch parameters, Table 1, are given in Table 2. A low-frequency inductive impedance of 10 Ohms, estimated from hardware [4] is assumed. As one can see intensity effects cannot be neglected.

Cycle	Ω_ϵ Hz	Ω Hz	$1/\Omega$ s
normal γ_{tr}	7.9	16.0	0.063
low γ_{tr}	12.1	37.6	0.027

Table 2: Debunching parameters

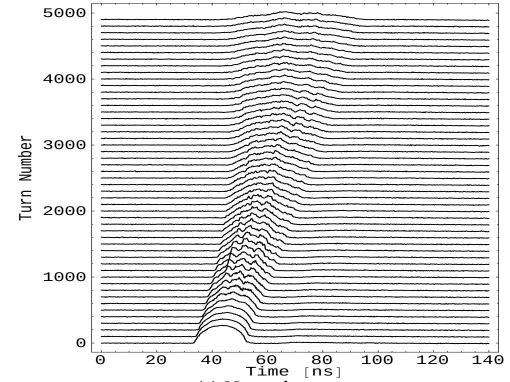
An approximate formula to describe debunching of a parabolic bunch under the influence of an inductive impedance above transition, valid at the beginning of debunching when $t < 1/\Omega$, is

$$\tau(t)/\tau(0) \simeq [1 + (\Omega^2 + \Omega_\epsilon^2)t^2]^{1/2}. \quad (2)$$

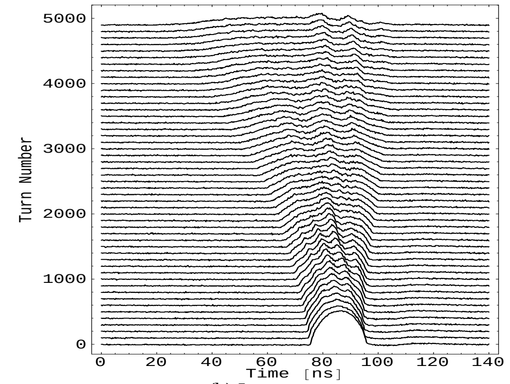
The bunch length increases by $\sqrt{2}$ for a time t given by

$$t_{deb} = 1/\sqrt{\Omega^2 + \Omega_\epsilon^2}. \quad (3)$$

Fig.2 shows the bunch profile turn by turn, corrected for pick-up response, for the two values of γ_{tr}. As expected from (1) the beam debunches faster for low γ_{tr}. Measurements on a number of practically identical bunches gave



(a) Normal γ_{tr}



(b) Low γ_{tr}

Figure 2: Mountain range display for normal and low γ_{tr}

t_{deb} = 52.7±2.6 ms for the normal γ_{tr} case and t_{deb} = 33.6±1.0 ms in the low γ_{tr} case.

In the normal γ_{tr} case the η is believed to be well known, 0.55×10^{-3}. For initial bunch parameters $\tau(0)$= 25 ns and Δp/p= 3.6×10^{-4}, the debunching time 33.6±1.0 ms then gives an inductive impedance of 16.9 ± 5.3 Ohms. This value is similar to the value of 18.7 Ohms found in [3] from the debunching of 5 ns bunches. These values are higher than the value of ∼10 Ohms that was estimated from the known machine elements [4]. Differences can occur due to instabilities which increase the momentum spread, suggesting increased impedance. It seems however that measurements of t_{deb} using bunch length are affected less than when using peak line density.

For low γ_{tr} assuming the impedance of 16.9 Ohms found above, we find η= 0.92±0.03×10^{-3}. Using the value of 10 Ohms, η= 0.96±0.03×10^{-3}, while for zero impedance η= 1.03±0.03×10^{-3}. These are all lower than the 1.3×10^{-3} expected from calculations with MAD for the nominal tune values. Taking into account a possible increase in momentum spread would push these values even further down.

4 INSTABILITY MEASUREMENT: TECHNIQUE AND RESULTS

The technique for measuring the resonant structure of the accelerator impedance is given in detail in [2]. Single bunches are injected into the machine with RF off. The longitudinal profile of the bunch is observed turn by turn using a wideband longitudinal monitor. The signals produced are analysed in frequency domain either directly using a spectrum analyser, or by FFT of the waveforms acquired by a digital oscilloscope. The bunch is observed during a time of the order of $1/\Omega$ and for each frequency the peak amplitude of the spectrum analyser signal is recorded. This is repeated for 10 injections and the average at each frequency point found. The bunch intensity is chosen such that the bunch is above threshold for normal γ_{tr} and the injected bunch length such that the spectral width of the stable bunch profile allows good resolution between peaks.

This procedure was carried out for the two cycles while keeping the injected beam parameters constant. The results are given in Fig.3.

The peaks of these spectra are centred at frequencies which correspond to resonant impedances with high R/Q. From numerical simulation it is known that the mode amplitude is a function of R/Q and N.

The mode spectrum is dominated by a peak around 200 MHz which is not reduced by changing η. Further peaks around the known machine impedances, [2], 400 MHz, 800 MHz, 1100 MHz, 1500 MHz and 1900 MHz are reduced by a factor in the range of 1.5 to 2.5. The same applies approximately for intermediate frequencies.

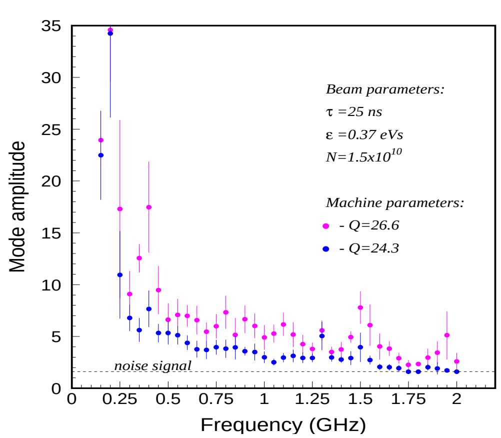
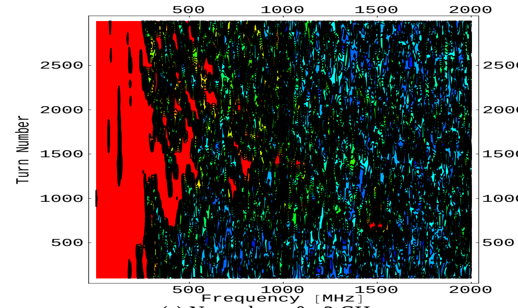
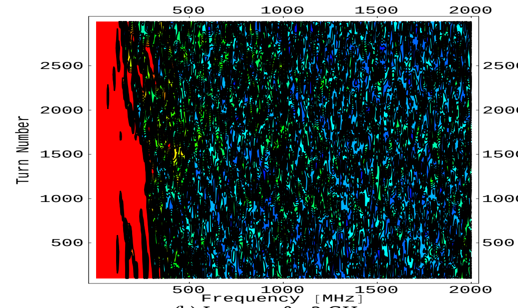


Figure 3: Bunch spectrum measured with the spectrum analyser at each frequency

The data from the FFT of the mountain range display shown in Fig.2 can be also be presented as contour plots as in Fig.4. The vertical axis gives the time evolution of the spectrum. The horizontal axis is the frequency and the amplitude at any time and frequency is colour coded. Regions with high mode amplitude are red, regions with low amplitude are blue. These figures allow the mode amplitude reduction mentioned before to be clearly seen, (see the reduction of the red hot spots when comparing the normal and low γ_{tr} data).



(a) Normal γ_{tr} 0 - 2 GHz



(b) Low γ_{tr} 0 - 2 GHz

Figure 4: Contour plots for the bunch spectrum.

5 CONCLUSIONS

It has been confirmed that one possible way to increase the microwave instability threshold at injection into the SPS is to lower the γ_{tr}. The method of changing γ_{tr} described here, while very effective for tests, is not acceptable operationally and solutions with new families of quadrupoles must be used.

We thank our colleagues in the PS for providing the stable injected beam and those in the SPS operations group for setting up the cycle.

6 REFERENCES

[1] G.Arduini, C.Arimatea, C.Despas, M.Lamont, L.Normann, W.Scandale, SL-Note-98-001 (MD)

[2] T.Bohl, T.P.R.Linnecar, E.Shaposhnikova, Phys. Rev. Letts. Vol78, Number 16, 21 April 1997.

[3] T.Linnecar, E.Shaposhnikova, EPAC, June ’96, Sitges, p1323

[4] L.Vos, CERN SPS/86-21(MS)