PS/RF/Note 92-17
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PS MACHINE DEVELOPMENT REPORT

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Subject: Production of flat-topped bunches (continued).

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1 Introduction

A flat-topped bunch profile may be produced by modifying the phase space distribution of the particles in the beam, specifically, by depopulating the central region of the phase space distribution. This has been achieved by phase modulating (at fixed energy) the main RF cavities while driving a single VHF cavity at a frequency which is offset by a constant Δf from a harmonic of the revolution frequency. The phase modulation frequency of the main RF cavities is made equal (or near) to the synchrotron frequency in order to excite particles of low synchrotron amplitude. The VHF serves to smooth out filaments in the excited bunch. Some longitudinal blow-up necessarily results.

2 Aims

The purpose of this MD was to produce flat-topped bunches at the injection energy of 1 GeV using the same technique[1] established previously at 3.5 GeV/c and to compare the transverse emittance blow-up induced by space charge effects for such a bunch shape with that for the normal, quasi-parabolic bunch profile.

3 Method

Machine conditions:
User: MD Cycle: G Harmonic number: 20
Working point: LEMD1, HEMD Supercycle: AACGBGDD
Beam intensity: 3.5×10^{11} protons per pulse in 1 bunch.

In this experiment, VHF cavity number 4 was driven using the manual test programme between C220 and C230 in the cycle, during which time the main RF cavities were phase modulated at a frequency f_{PM} and amplitude (depth) A_{PM} for an integer number, n_{PM}, of modulation periods starting from C221. The parameters Δf, V_{VHF}, f_{PM}, A_{PM} and n_{PM} were optimized for the most rectangular bunch profile and the resultant transverse emittances measured using the flying-wire scanner. In order to increase space charge density, the RF voltage was subsequently raised from the ~44 kV matching the PSB to ~176 kV to shorten the bunch during 800 ms on the long injection ledge then lowered back to ~44 kV, when the transverse emittances were measured again. A working point known to be susceptible to space charge induced transverse emittance blow-up was deliberately chosen, viz., $Q_h=Q_v=6.22$.

For the purpose of comparison, a controlled longitudinal blow-up was also employed to produce a bunch of the same length (prior to the voltage change) whilst preserving its original, quasi-parabolic shape. This conventional blow-up used the standard BU1 parameters at a total voltage of ~17 kV between C216 and C234 with all the bunch flattening features disabled.

The bunch profile was recorded by means of the "Bunch Observation System" (BOS). Modifications to the BOS program were implemented to provide a plot of phase space density (by an Abel transformation[2] of the bunch profile) and to evaluate a figure of merit expressing the extent to which the profile was rectangular. This latter "bunch shape quality factor", QF, was devised in analogy with the familiar bunching factor and defined as the ratio of the mean to the peak line charge density, where the mean is taken over $\pm\sqrt{3}$ standard deviations about the centre (mean) of the bunch rather than over the entire bucket length or machine circumference. For a perfectly rectangular profile, QF=1 and, unlike the bunching factor, QF is largely insensitive to the aspect ratio of the bucket.

4 Experimental Results

The flat-topped bunch observed at C257 is shown in figure 1 together with the unmodified (A_{PM},V_{VHF}=0) bunch profile.

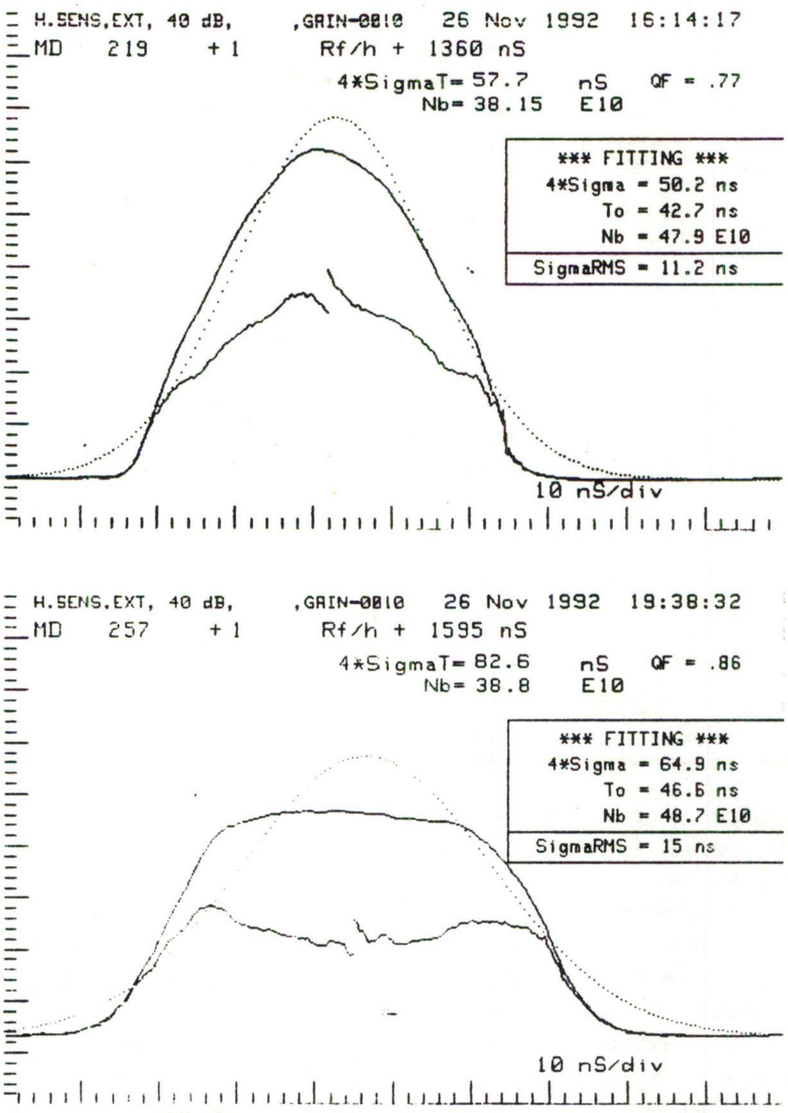

Figure 1. Initial and flat-topped bunch profiles.

The flat-topped bunch of figure 1 was obtained with Δf=7.0 kHz (with respect to the 479th harmonic of the 417.40 kHz revolution frequency), V_{VHF}~6.5 kV, f_{PM}=1.67 kHz, A_{PM}=25° and n_{PM}=7. QF improves from 77 to 86% at the cost of an increase in bunch length from about 50 to 62 ns.

The Abel transform is plotted at roughly half the height of the bunch profile and is sensitive to the slope of the latter, particularly at the centre of the bunch. The transformation assumes constant two-dimensional phase space density at given synchrotron amplitude, i.e., that the bunch is perfectly matched. Hence there is discontinuity between the left- and right-hand phase space density curves when the slope at the centre of the profile is non-zero. However, the depopulation of the middle of the modified distribution remains evident.

The subsequent fourfold increase in RF voltage reduces the bunch length by a factor of √2, but QF is little changed (see figure 2). While the return to the injection voltage produces a bunch which is remarkably similar to that at the outset (see figure 3, cf. figure 1), indicating that the depletion of phase space density does not prejudice bunch stablility.

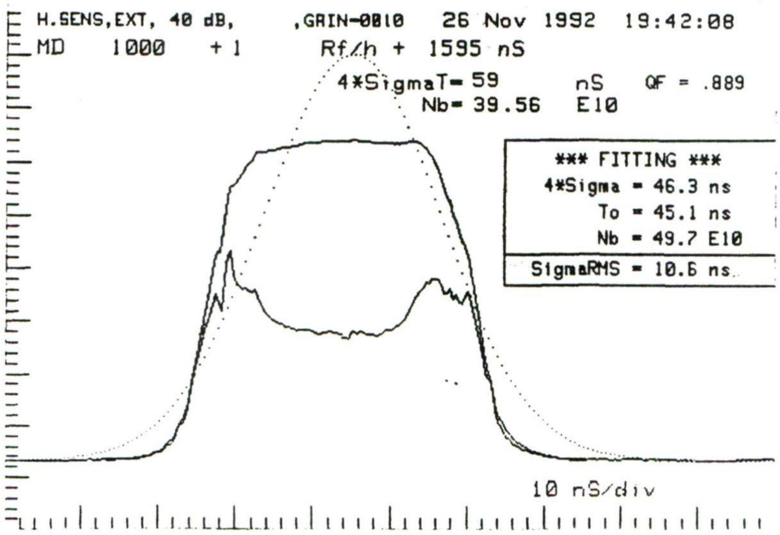

Figure 2. Flat-topped bunch profile at elevated RF voltage.

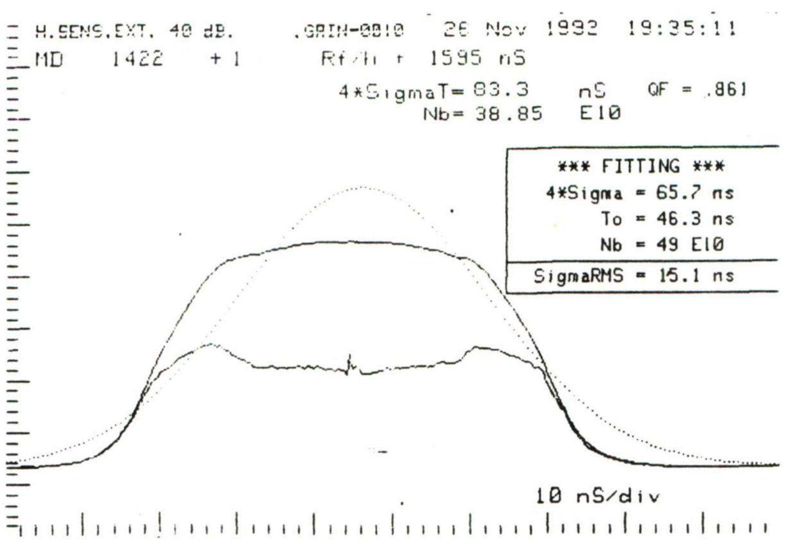

Figure 3. Flat-topped bunch profile after the end of the RF voltage increase.

A series of flying-wire measurements at C257 (corresponding to figure 1) and C1422 (corresponding to figure 3) yielded typical transverse emittances of ε_h=8.48, ε_v=7.09 and ε_h=9.16, ε_v=9.11 π.mm.mrad, respectively. That is, an overall (ε_h+ε_v) emittance growth of 17% during the 800 ms at increased incoherent tune spread.

Starting with a 62 ns quasi-parabolic bunch at C257 (see figure 4), the same voltage programme yielded typical emittances of ε_h=8.58, ε_v=7.07 and ε_h=10.1, ε_v=9.98 π.mm.mrad at C257 and C1422, respectively. That is, an overall emittance growth of 29%. (Negligible emittance growth was observed in the absence of the RF voltage increase.)

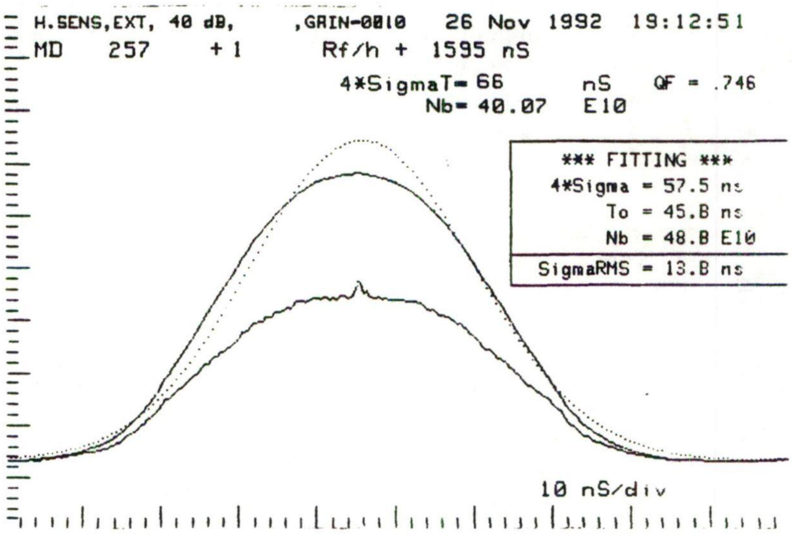

Figure 4. Quasi-parabolic bunch profile before the RF voltage increase (cf. figure 1).

Thus, a significant reduction of space charge induced transverse emittance blow-up is achieved under these conditions due to the increased (by a factor of about 1.3) bunching factor of the flat-topped bunches.

5 Conclusions

Flat-topped bunches have been reproducibly generated in the PS by combining the effect of a phase modulation of the RF with some voltage at a VHF frequency which is slightly offset from a harmonic of the beam revolution frequency. The method affords a reduction of space charge induced tune shift which may be of interest in the LHC era.

References

[1] R. Garoby, S. Hancock, J-L. Vallet PS/RF/Note 92-8.

[2] P.W. Krempl, MPS/Int. BR/74-1.