PS/RF/Note 92-15
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PS MACHINE DEVELOPMENT REPORT

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Participants: R. Garoby, S. Hancock.

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

Date: Tuesday 13 October, 12:00 to 19:00.

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1 Aims

The purpose of this MD was to demonstrate the reproducibility of the flat-topped bunches of the MD of 30 June[1], to quantify the improvement over the normal quasi-parabolic bunch profile and to investigate whether the resultant depletion of phase space density at the centre of the bunch prejudices bunch stability under closed-loop conditions.

2 Method

Machine conditions:			
	User: MD	Cycle: C	Harmonic number: 20
	Working point: LEINT, HEC		Supercycle: AACCCCC
	Beam intensity: 1.6×10^{12} protons per pulse in 5 bunches.		

The technique established in [1] was again employed on the 3.5 GeV/c magnetic ledge, but, instead of using external frequency synthesizers, the standard low-level hardware provided f_{RF} (~9 MHz) and f_{VHF} (~200 MHz) except that the latter was fed to a single VHF cavity via a precision phase shifter. The magnitude of the inserted phase shift was modulated to produce a constant frequency shift, Δf, so that:

$$f_{RF} = h_{RF} f_{REV}$$
$$f_{VHF} = h_{VHF} f_{REV} + \Delta f$$

with h_{RF}=20, h_{VHF}=433 and f_{REV}=461.46 kHz. The VHF cavity (number 7) was driven using the BU2 blow-up parameters between C340 and C400 in the cycle, during which time the main RF cavities were phase modulated at a frequency f_{PM} and amplitude (depth) A_{PM}.

The resultant bunch profile was recorded 40 ms later (i.e., at C440) by means of the "Bunch Observation System" (BOS) in the MCR. 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 insensitive to the aspect ratio of the bucket.

3 Experimental Results

Flat-topped bunches could not be reproduced using the same parameter values as in [1]. Here, suspicion rests with the observation of a 300 Hz ripple in the low-level hardware of the phase loop. However, scanning over the four principal parameters (Δf, f_{PM}, A_{PM} and V_{VHF}) did yield an optimum. This is shown in figure 1 together with the unmodified (A_{PM},V_{VHF}=0) bunch profile. Table 1 lists the corresponding bunch characteristics as well as those of the (main) RF bucket.

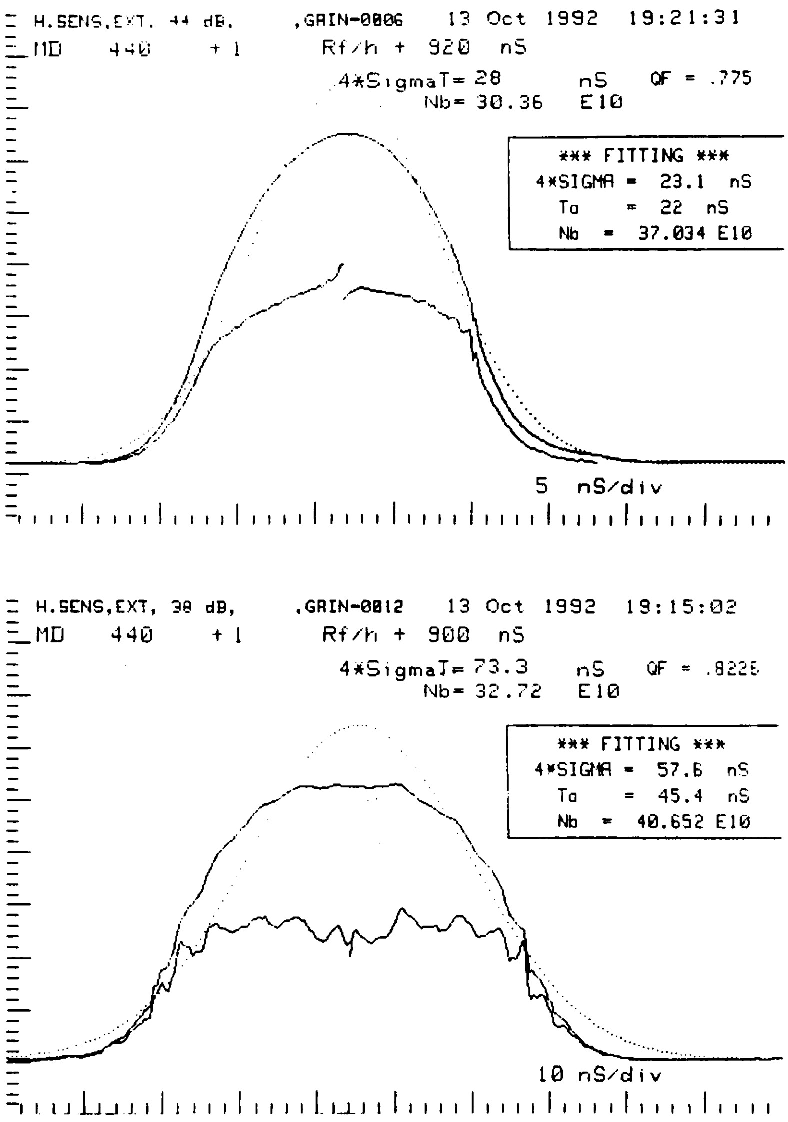

Figure 1. Initial and final bunch profiles.

	Length/[ns]	Area/[eV.s]	($\Delta p/p$)/[10^{-3}]
Bucket (V_{RF}=85 kV)	108.4	2.15	4.53
Initial Bunch	25	0.2	1.6
Final Bunch	60	1.1	3.5

Table 1. RF bucket and bunch characteristics.

The flat-topped bunch of figure 1 was obtained with Δf=3.8 kHz, f_{PM}=755 Hz, A_{PM}=12.5° and V_{VHF}≈15 kV. The profile is less "smooth" than that produced previously and this causes large fluctuations in the Abel transform (which is plotted at roughly half the height of the bunch), to the point that the expected reduction of phase space density at times (radii) near the bunch centre is barely confirmed. The transform is particularly sensitive to the slope at the centre of the profile, hence the discontinuity between the left- and right-hand phase space density curves of the initial bunch.

The quality factor is increased, but only by a few percent. This is in close agreement with a computer simulation modelling the earlier MD.

Figure 2 shows oscilloscope traces of the phase between the RF cavities and the beam and of a detected longitudinal pick-up signal from C280 to beyond the time when the beam was dumped internally at the end of the 3.5 GeV/c ledge. The phase modulation "burst" is evident in the former, as is the spurious 300 Hz ripple. The detected pick-up signal indicates that bunch lengthening is largely complete halfway through the 60 ms process. However, the BOS reveals that a strong high-frequency structure persists beyond 30 ms.

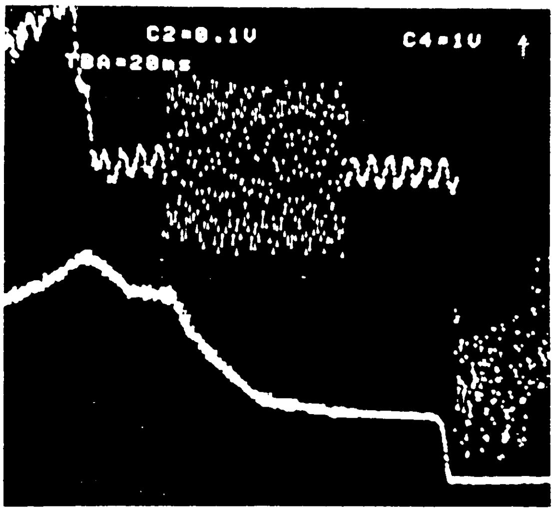

Figure 2. Phase discriminator (upper trace) and detected pick-up signals.

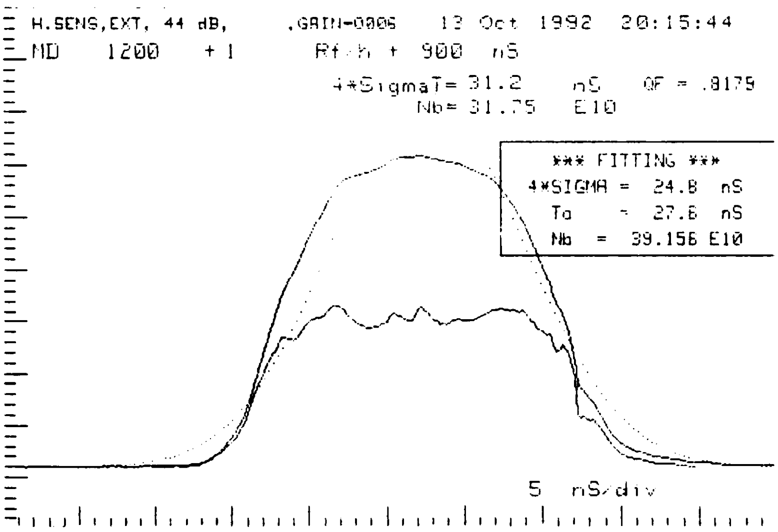

Figure 3. 26 Gev/c bunch.

Figure 3 shows the bunch profile after the acceleration of flat-topped bunches to 26 GeV/c. The result is arguably less flat than at 3.5 GeV/c, but QF is little reduced.

The bunch profile was not improved by driving the VHF cavity with a double sideband signal, that is with $f_{VHF}=h_{VHF}f_{REV} \pm \Delta f$. However, nor was it significantly degraded by increasing the beam intensity from $\sim 3\times10^{11}$ to $\sim 8\times10^{11}$ protons per bunch.

4 Conclusions

Flat-topped bunches have been reproduceably 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.