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PS MACHINE DEVELOPMENT REPORT

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ACCELERATION OF 4 RECOMBINED BOOSTER RINGS IN THE PS USING THE R.F. DIPOLE AND THE QUASI-ADIABATIC LONGITUDINAL MERGING TECHNIQUE

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1. SUMMARY AND CONCLUSIONS

In previous operations the R.F. dipole method [1], [2] and the adiabatic longitudinal merging [3] have been tested separately. The aim of the present MD experiment was to test the two techniques together in order to recombine the beams from 4 PSB rings into 5 bunches in the PS and eject these with a good efficiency onto the antiproton production target. This to provide a higher intensity production beam for the AA complex.

The beam under study consists of 20 bunches (4 PSB rings) recombined in the PSB-PS transfer line by a RF dipole into 10 PS buckets. The 10 resulting bunches are then merged into 5 buckets by the quasi-adiabatic technique at 3.5 GeV/c, and squeezed into a quarter of the PS circumference at 26 GeV/c.

Under these conditions the limit of 2 E12 protons lost per pulse was reached for an intensity of 1.61 E13 protons per pulse in the PS (1.5E13 protons per pulse were achieved in the previous scheme). The emittances of the ejected beam were 1.7 pie mm mrad (H) and 1.2 pie mm mrad (V).

2. BOOSTER STUDIES

The main task for the booster in this experiment was to extend the experience gained with the R.F. dipole recombination mode to all four rings. This implies the two principal tasks :

(i) Application of the R.F. procedures developed for Rings 2 and 3 using the h=10 cavities to shorten booster bunches to all four rings.

(ii) Careful adjustment of the R.F. recombination and of the trajectories for all four rings.

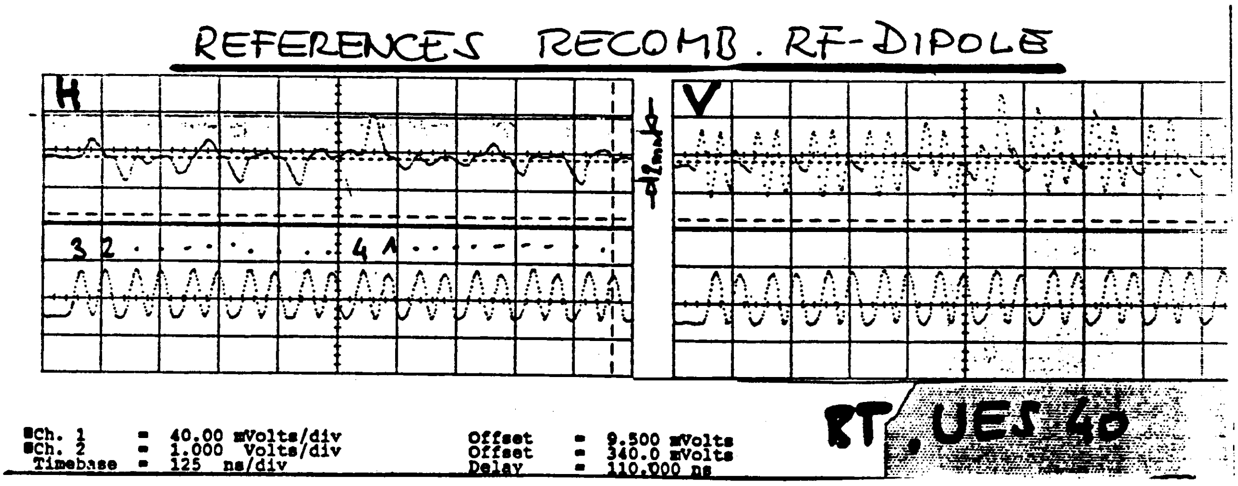
The User MD was composed MD = C1GEV*QMAX*IME*RFDIP, while the remaining users use QHIGH,IHIGH (SFT) or QMAX,IMAX (AA).

(i) The underlying ideas and the principle of this R.F. procedure are described in Ref.[1]. Practically it consists in introduction of a delay in the signal path of the h=10 R.F. such that the 2nd harmonic voltage is in antiphase with the fundamental at injection to flatten the bunches an in phase at transfer energy to tighten them. At present this is achieved by a manually controlled delay which is not ppm, i.e. it affects all cycles using h=10 cavities. Ppm is done via the voltage ratio (between the 2 R.F. systems) programme (reducing the 2nd harmonic amplitude to an insignificant fraction on all cycles wanting normal bunch length. Adjustment of this voltage programme is fairly critical and time-consuming for four rings. Table I shows the resulting bunch lengths and respective voltages at the end of the cycle.

Ring	1	2	3	4
Bunch Length (ns)	46	46	46	47
VRF, h=5 (kV)	11.2	12.5	12.2	11.2
VRF, h=10 (kV)	4.1	3.6	5.5	7.1

Table I : Bunch lengths and R.F. voltages for the four PSB rings relative phases, which in turn are imposed by stability problems of the beam control system. Typical transverse normalized emittances of the circulating beam for N= 5E12 p/ring at 1 GeV are Ex* = 36 pie, Ey* = 18 pie mm mrad.

(ii) Adjustment of the transfer and the R.F. recombination was eased by observation of the analog signals of the transfer pick-ups with an HP 54111 1 GHz sampling oscilloscope (Figure 1).



Ch. 1 = 40.00 mVolts/div
Ch. 2 = 1.000 Volts/div
Timebase = 125 ns/div
Offset = 9.500 mVolts
Offset = 340.0 mVolts
Delay = 110.000 ns

Figure 1 : Sum, Delta H and Delta V signals of BT.UES40 showing all four RF recombined rings

3. CALCULATION OF THE BOOSTER TO PS TRANSFER MATCHING

The non-rectangular pulse shape of the R.F. dipole in the Booster to PS transfer line modifies the vertical betatron ellipses : the y' distribution width at the dipole and consequently the vertical emittance, increase by a factor 1.44 [3]. Continuity of the beam envelope implies a reduction of the vertical beta value by the same factor, whereas alpha remains unchanged.

This situation requires different quadrupole settings in the BT transfer line, and minor changes to the BTP line, as is shown in table II. Both matching calculations were allowed to vary 2 BT quadrupoles (40 and 50) and 5 BTP quadrupoles (20 to 60) in order to match the beta functions precisely in both planes and the horizontal dispersion function approximately.

	20 bunches	R.F. dipole
BT .QNO40	+229.9	+233.9
BT .QNO50	-149.5	-157.9
BTP.QNO10	0.0	0.0
BTP.QNO20	117.6	117.6
BTP.QNO30	108.5	109.0
BTP.QNO40	142.7	142.8
BTP.QNO50	121.6	121.7
BTP.QNO60	146.6	146.6

Table II : Booster to PS transfer matching, with and without R.F. dipole

4. MEASUREMENT OF THE PSB-PS MATCHING

Since the injection of each of the 4 Booster rings cannot be controlled individually in the PS, the tuning of the 4 Booster ejections has to be done with care, while monitoring the trajectories in the transfer line and in the PS ring. After the ejection tuning the residual vertical oscillations were around 3 mm for bunches 10 and 11 and less for the other bunches.

The matching between the PSB and the PS was measured using the three groups of sem-grids in straight sections 48, 52 and 54. The length of the mismatch vector was then calculated using the beam profile observations (perfect matching leads to zero length mismatch vector). Detuning a matching quadrupole caused immediately the mismatch vector length to increase drastically. Table III summarizes the characteristics of the 1 GeV beam at injection in the PS (the emittances are non normalized). To reduce the beam intensity, all measurements were performed using only two PSB rings.

	radial	vertical
emittance at 2 sigma [pi mm mrad]	16.3	8.7
emittance blow-up (due to mismatch)	28 %	17 %
mismatch vector length	0.24	0.16

Table III : Measured physical emittances and mismatch vectors

5. LOW-ENERGY WORKING POINT

The operational characteristics of the beam were (user MD) : Cycle C, LEMD2, HEC, SWP, PROT, FE16A. Exploration of the Qh-Qv diagram at 1 GeV with beams of intensities around 1.85E13 protons ejected from the PSB showed that the machine tune was acceptable (i.e. at most 4E12 protons were lost per cycle) inside the domain :

$$6.12 < Qh < 6.25 \quad \text{and} \quad 6.29 < Qv < 6.33$$

The losses increase drastically when the tune lies outside this area. Consequently, the working point was tuned to Qh=6.14 and Qv=6.33 at low energy.

6. LONGITUDINAL PHASE PLANE ADJUSTMENTS (R.F.)

6.1 Capture of 2 bunches per bucket at injection

Reminder : 2 PSB bunches are injected in each of 10 PS buckets (h=20). 10 high intensity bunches filling 1/2 of the PS remain after filamentation.

- With 1 GeV Blow-up "Off" and no radial steering at low energy minimisation of capture losses using the voltage program (Vrf LE) (Figure 2).
- Slight improvement after bringing the distance between bunches from 180 down to 160 R.F. degrees.

- Fine adjustment of the 1 GeV Blow-up to smooth the final bunch shape and stabilise the beam up to 3.5 GeV/c while avoiding losses due to the lack of acceptance.

- Adjustment of the radial perturbation PERLE1 (active from 1 to 3.5 GeV) to minimise beam losses.

- Efficiency was later shown to be rather insensitive to the R.F. phase at injection.

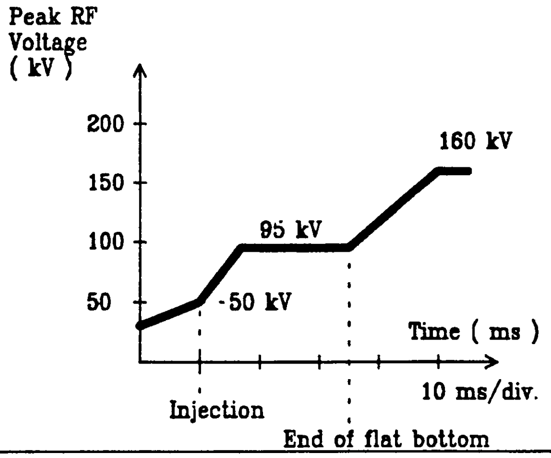


Figure 2 : Voltage program at low energy (h=20)

6.2 Quasi-adiabatic beam merging at 3.5 GeV/c

Reminder : 10 bunches on h=20 are merged into 5 on h=10 using a quasi-adiabatic process.

- No fine tuning of the merging parameters was necessary. The ones used when merging "ordinary PSB bunches" proved fully adequate.

- Adjustment of the 3.5 GeV/c Blow-up : a 10 % reduction of blow-up was needed to compensate for the larger emittance of the original bunches.

6.3 Acceleration of 5 bunches on harmonic 10 up to 26 GeV

Reminder : 5 bunches filling 1/2 of the PS are accelerated across transition energy up to 26 GeV.

- Modification of the radial perturbation PERLO1 applied around transition crossing. Start is as near as possible from transition (C 507), but amplitude is normal (4.5 mm).

- Demonstration of the detrimental effect of transient cavity beam-loading at transition. 20 kV of h=11 are applied to approximately compensate for the different beam induced voltages experienced by the 5 bunches (Figure 3). H=11 phase is controlled to provide a proper compensation on both sides of transition.

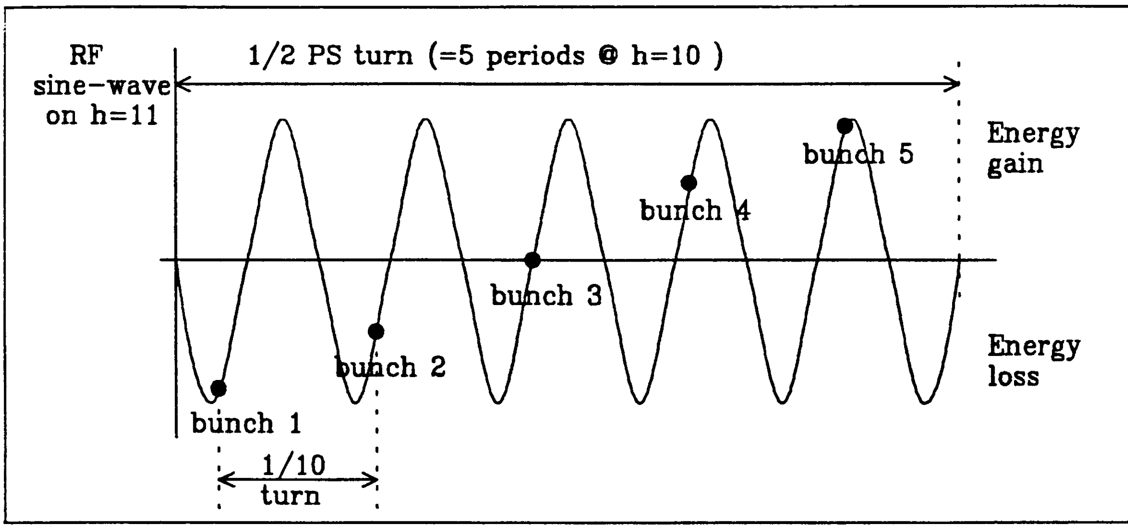
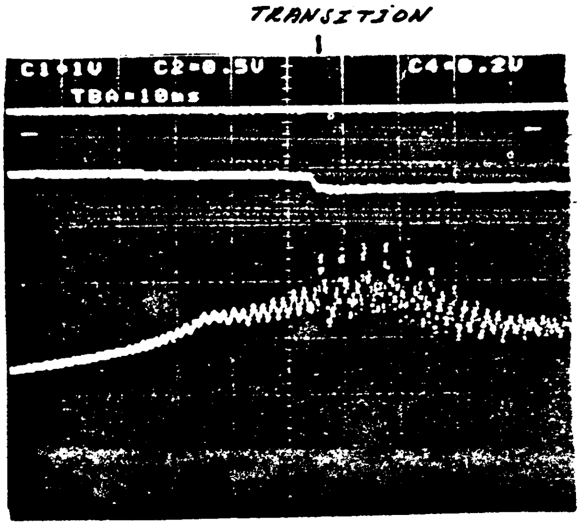


Figure 3 : Compensation of transient beam-loading with an h=11 R.F.



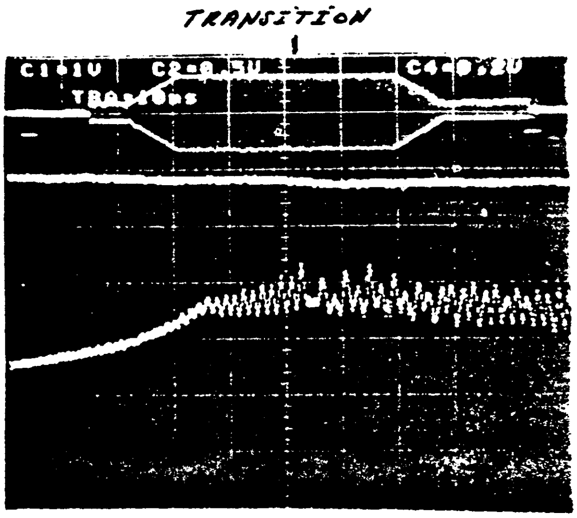
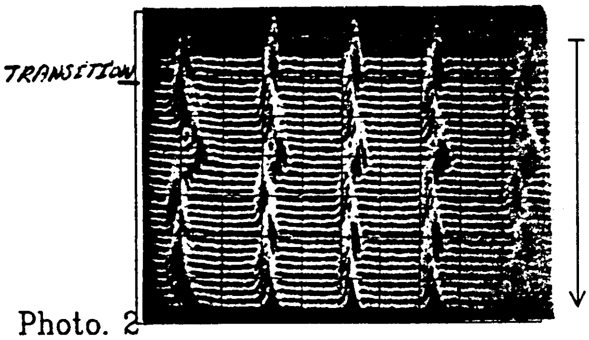


Photo.1

Without h=11 RF

Photo. 3

With h=11 RF



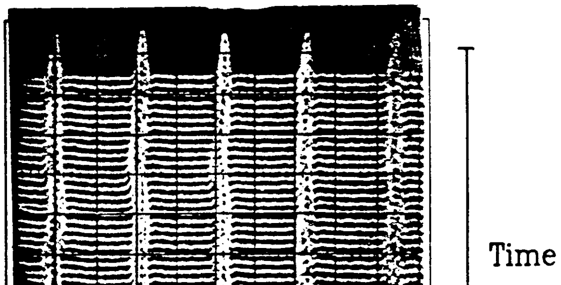


Photo. 2

Photo. 4

Photos 1 and 2 show the beam behaviour without h=11.
Photos 3 and 4 illustrate the effect of the h=11 voltage.

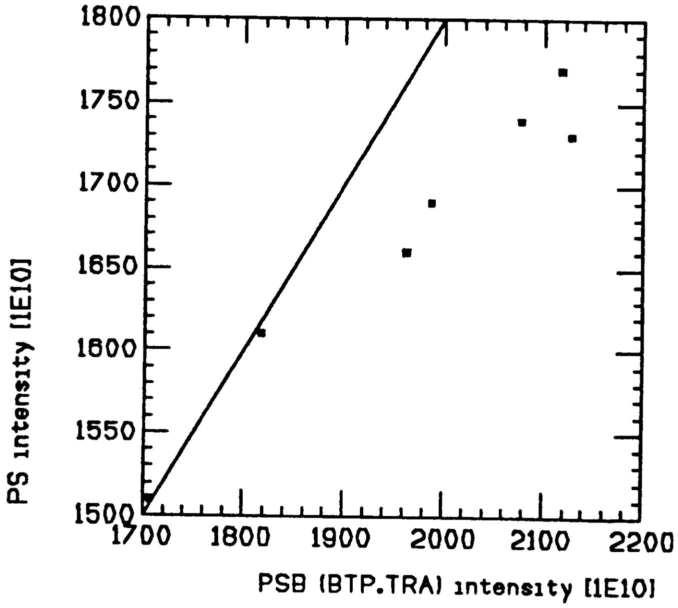
6.4 <u>"Bunches batch compression" at 26 GeV</u>

Reminder : The harmonic number "seen" by the 5 adjacent bunches is slowly increased from 10 to 20, so that the bunches finally occupy 1/4 of the PS circumference.

- When intensity rose above the level usually encountered while operating with 2 PSB rings (around 1.5 e13ppp) some phase adjustments had to be slightly modified to correct for the beam-loading effect.

7. BREAKDOWN OF THE LOSSES

Figure 4 shows various beam intensities measured in the PS, as a function of the PSB beam intensities. The limiting curve where losses are equal to 2E12 p is shown for comparison (continuous line). Table IV shows the breakdown of the losses for measured proton beam intensities of 1.82E13 in the PSB and 1.61E13 in the PS.



PS BEAM INTENSITY VS. PSB BEAM INTENSITY

fast loss at 1 GeV injection	25 E10 p
losses on the 1 GeV magnetic flat bottom	25 E10 p
captur loss measured at the end of the 1 GeV flat bottom	50 E10 p
losses at the highest magnetic field value	25 E10 p
losses on the 3.5 GeV/c magnetic flat bottom	25 E10 p
losses at the transition energy	50 E10 p
total losses	200 E10 p

Table IV : Breakdown of the beam losses in the PS

Studies have also been performed to try all combinaisons of merging two PSB rings (i.e. rings 3-2, 4-1, 3-1 and 3-2) in order to make evidence of a "weaker" PSB ring. No significant conclusion can be drawn from these measurements.

8. TT2 EMMITANCE MEASUREMENTS

The envelope of the beam ejected at 26 GeV towards the AAC target is determined by the energy spread and the transverse emittances. The beam size is measured with 3 sem-grids in the TT2 line. The analysis is done for several energy spread values, each time comparing the measured betatron ellipses with the nominal optics of the line. The best agreement was obtained for a deltap/p spread of 1.5 E-3 at 2 sigma. The emittances were estimated at 1.7 pi (H) and 1.2 pi (V) mm.mrad for a 1.7 E+13 proton beam.

These values are to be compared with the emittances 1.8 pi (H) and 1.3 pi mm.mrad (V) of June 1989 for a beam of comparable intensity, but without use of the R.F. dipole.

9. REFERENCES

[1] R. Cappi et al., CERN PS 89-26 and 1989 P.A.C. at Chicago.

[2] K. Schindl, PS/BR Note 84-4

[3] R. Garoby, CERN PS 89-43