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PS MACHINE DEVELOPMENT REPORT : PREPARATION OF THE NOMINAL PRODUCTION BEAM FOR THE AD

R. Garoby (auteur), S. Hancock, A. Ozturk, J-C. Perrier, J-L. Vallet

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PS MACHINE DEVELOPMENT REPORT

Participants : R. Garoby (Author), S. Hancock, A. Ozturk, J.C. Perrier, J.L. Vallet

Subject : Preparation of the nominal production beam for the AD

Dates : MD sessions between October and December 1998

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1. Introduction

The requirements of the AD [1,2] concerning the anti-proton production beam ejected at 26 GeV/c from the PS are similar to the ones of the AC:

- the largest possible number of protons must be sent to the target, and the beam burst length must not exceed ¼ of the PS circumference,
- the distance between bunches must be a multiple of the period on h=20 (in the PS),
- bunch length must be smaller than 25 ns for the bunch rotation to provide an adequate fast reduction of the energy spread of the pbar beam in the AD,
- the beam must be synchronised to a reference at the revolution frequency to permit multi-batch filling of the AD.

Thanks to the modifications made to the RF systems of the PSB and PS for the needs of LHC, these specifications can be achieved with improved efficiency and less gymnastics than before. The process is the following [3]:

- 4 bunches from the 4 PSB rings are transferred into 4 consecutive buckets in the PS on h=8, filling ½ a turn,
- these 4 bunches are accelerated up to 26 GeV/c on h=8,
- at 26 GeV/c, “Batch Compression” [4] is exercised and the harmonic number “seen by the beam” is quasi-adiabatically increased from 8 to 20 in steps of 2.
- Synchronisation has to take place before the end of the flat-top, and bunch rotation is triggered by a voltage step before ejection.

Development of new electronics for the beam control and for the “One Turn Delay Feedback” of the ferrite cavities [5] started in 1996 and operational modules were installed in the course of 1998. Tests with beam have then been possible since October. This report describes the results obtained until the end of 1998 and the subjects and planning of the work for 1999.

2. Experimental conditions

2.1 PLS

PLS PS:
User: MDAD Cycle: C Harmonic number: HSWP

2.2 Beam control

The architecture of the beam control (figure 1) is based upon the need to precisely control the phase of the many different RF harmonics sent to the 11 ferrite cavities. It relies upon special features included into the direct digital synthesizer function called “Multi Harmonic Source” (M.H.S. [6] in figure 2) to help simplify cabling and adjustment.

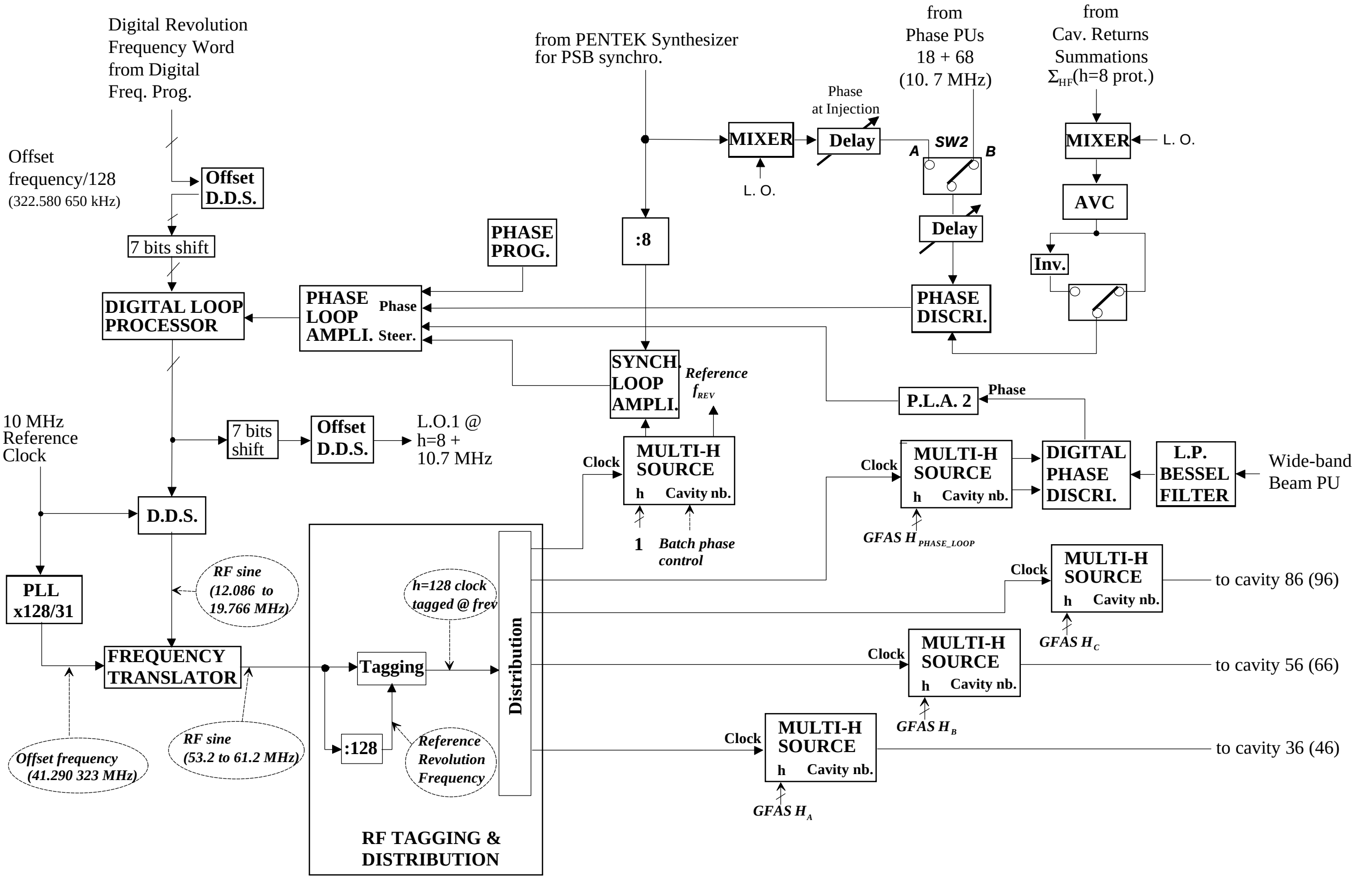


Figure 1: Beam control block diagram

The basic principles are the following:

- an h=128 clock is driving all RF sources (fclock < 62 MHz). It is “tagged” at the revolution frequency (fclock/128), so that every synthesizer downstream can be locked without ambiguity. The frequency of this clock is modulated via a DLP by the signal from the beam phase loop (see figure 1).

- an M.H.S. is dedicated to each cavity (11 units in total, only 3 being represented in figure 1). Smooth frequency control is provided, with the full 16 bits resolution of the serial output from a GFAS.

- the phase accumulator in every M.H.S. is reset when its harmonic control word reaches an integer value. The reset is synchronous with the revolution train derived by de-tagging the h=128 clock. Phasing of cavities is then guaranteed on any harmonic, without the need for any external action.

- inside the M.H.S., a phase offset obtained by multiplication of the azimuthal position of the cavity with the harmonic number is subtracted from the phase accumulator output. Compensation of the phase shift due to the time of flight between cavity gaps is then automatically guaranteed.

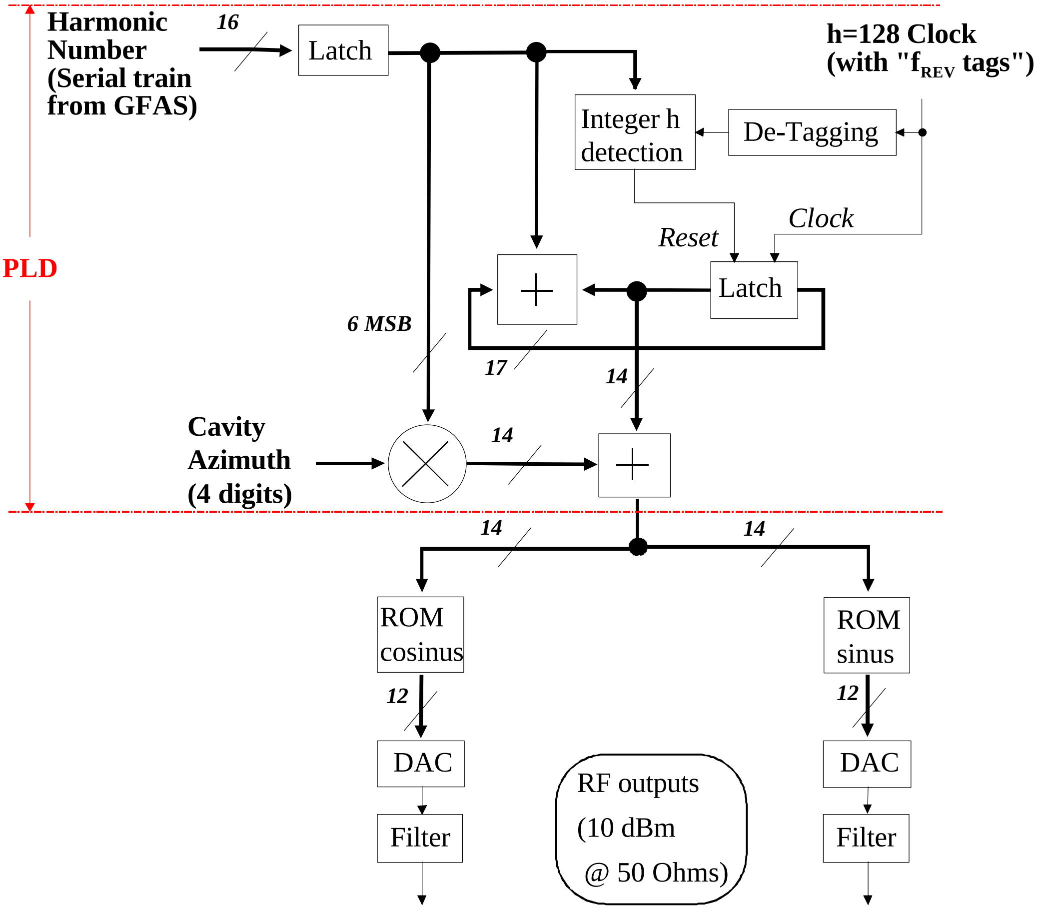


Figure 2: Multi Harmonic Source

A Digital Phase Discriminator (D.P.D. [7] in figure 3) function has also been specially developed to measure the beam phase in real time during the changes of harmonics and provide the possibility to have a phase loop closed during the gymnastics of Batch Compression. An M.H.S. driving the sine and cosine inputs of the module determines the frequency where the phase is measured. The results of mixing the beam PU signal with $\sin(h\omega_{REV}t)$ and $\cos(h\omega_{REV}t)$ are low-pass filtered, and provide the phase information after rectangular to polar conversion.

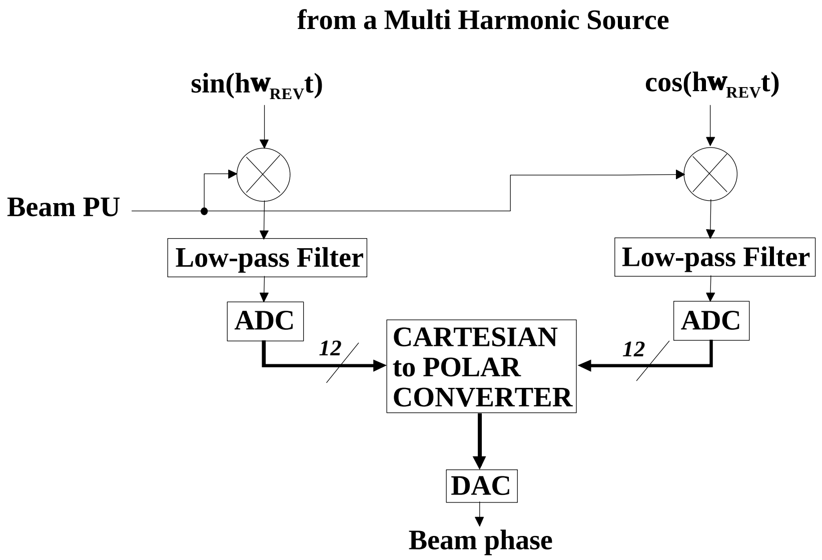


Figure 3: Digital Phase Discriminator

2.3 System operation

The system operates as follows:

-1. Before injection the reference f_{REV} (MHS operating on h=1) is DC phase locked onto the injection synthesizer divided by 8, to guarantee the position of the beam with respect to this reference after injection. 7 ms later the main h=8 phase loop locks the cavity sum signal on the injection synthesizer and the h=1 synchro. is stopped.

-2. 20 µs after injection, the h=8 phase loop is switched onto the beam PU signal (SW2), and the Phase Loop Amplifier (P.L.A.) is set to AC coupling. The radial loop is started at the same time. Both loops control the beam and permit acceleration on h=8 up to 26 GeV/c.

-3. On the 26 GeV/c flat-top the radial loop is first turned off (the radial error signal is not usable during the gymnastics of Batch Compression). Then another AC coupled beam phase loop is activated using the phase measurement from a D.P.D. and the h=8 phase loop is switched Off a few ms later. The frequency (the harmonic number) at which the beam phase is measured is controlled by a dedicated GFAS (HPL) and changes in steps during the batch compression.

-4. For the needs of Batch Compression, the cavity voltages are controlled in 4 groups:

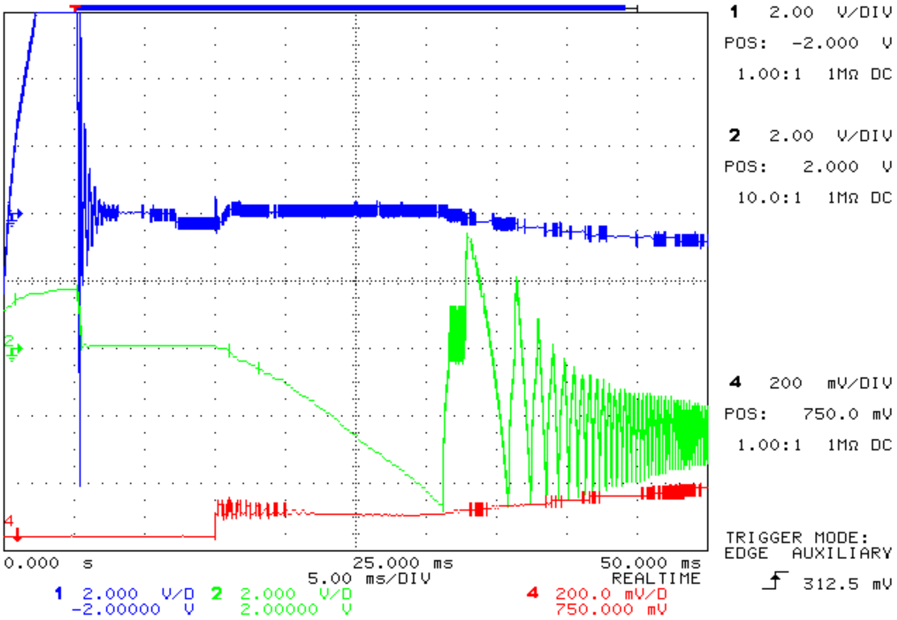
Group A (Vprog line 4): C36 and 46
Group B (Vprog line 5): C56 and 66
Group C (Vprog line 6): C86 and 96
Group D (Vprog line 3): C51, 76, 81 and 91.

The frequencies of the signals sent to the cavities are similarly controlled in 3 groups, the difference being that the voltage groups B and D have the same frequency. Gap relays will be exercised in the future, but they were not used in 1998.

3. Experimental results

3.1 Capture and acceleration

Synchronisation before injection, first on h=1, then on h=8, followed by beam injection is illustrated in figure 4 (Oscilloscope in envelope mode).



1: Phase discri. h=8 (50 mV/deg)

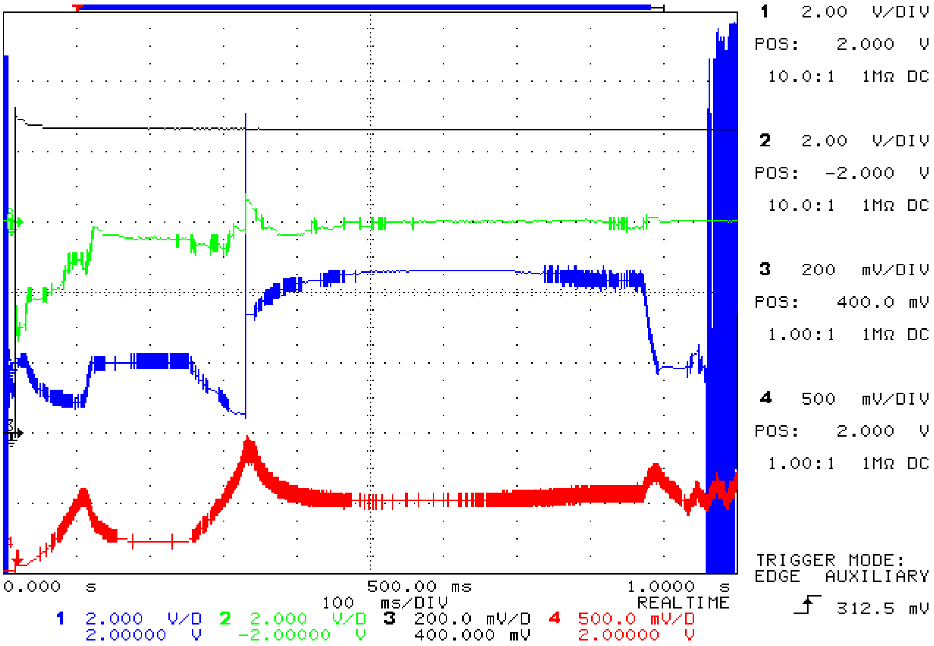
2: Phase discri. h=1 (25 mV/deg)

4: Detected PU

[Trigger C200]

Figure 4: Injection

Characteristic signals during acceleration of 9 × 10^{12} ppp are shown in figure 5. For stability up to the high energy flat-top, the longitudinal emittance per bunch (h=8) is increased up to 2 eVs (at 1.4 × 10^{13} ppp) applying a controlled longitudinal blow-up at 3.5 GeV/c.



3: Beam transfo. (10^{13} p/V)

2: Radial corr. (Steering)

1: Phase discri. h=8 (50 mV/deg)

4: Detected PU

[Trigger C200]

Figure 5: Acceleration

More details on the detected PU signal are visible in figure 6, where the accelerated intensity is at the record value of 1.35 × 10^{13} ppp. Signs of bunch shape oscillations appear soon after transition, indicating that the operation of the Hereward damping and the cavity voltage should be finely adjusted. The evolution of bunch height at 26 GeV/c is characteristic of a correct operation of the Batch Compression process.

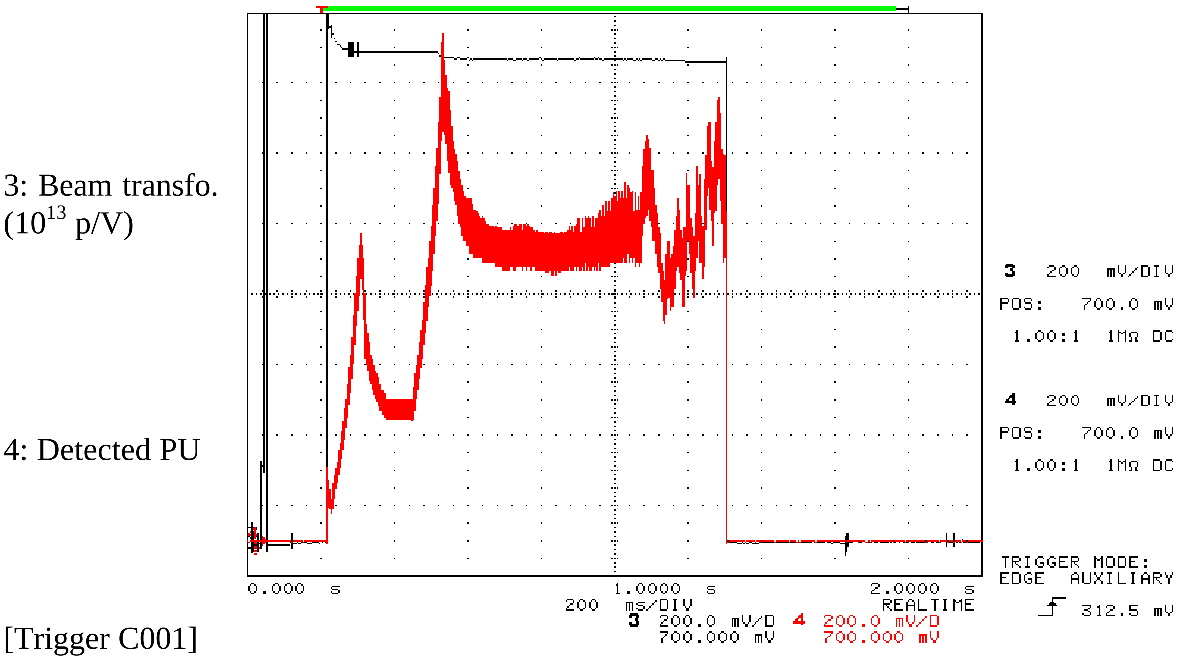


Figure 6: Acceleration of 1.35 ´ 10^{13} protons

3.3 Batch Compression at 26 GeV/c

The voltage programmes and the harmonics during the Batch Compression are shown in figure 7.

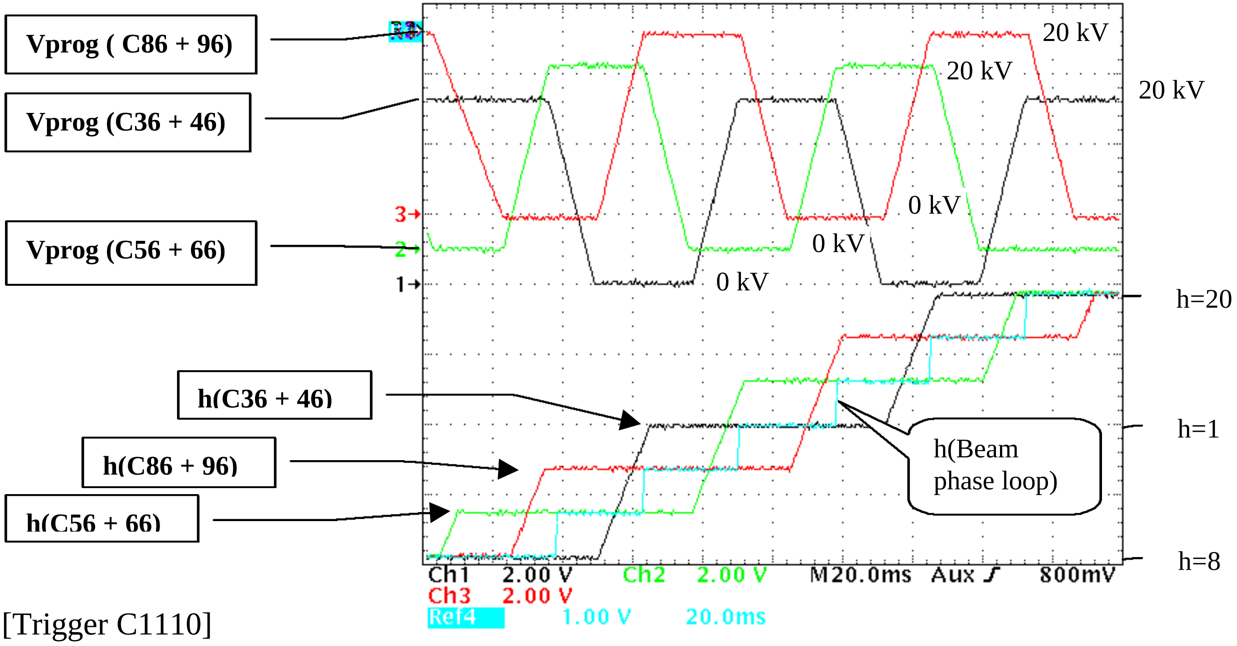


Figure 7: Acceleration of 1.35 ´ 10^{13} protons

The voltage on cavities 51, 76, 81 and 91 is not shown because it is at 0 kV during the full process. As can be seen, the harmonic number of the beam phase loop changes in steps in the middle of each transition from one harmonic number to the next. The beam phase is then always measured at a frequency where the amplitude of the beam signal is large.

At high intensity (> 5×10^{12} ppp) the voltage induced by the beam in the cavities becomes troublesome and the different bunches experience different perturbations (see figure 8 recorded at 9×10^{12} ppp).

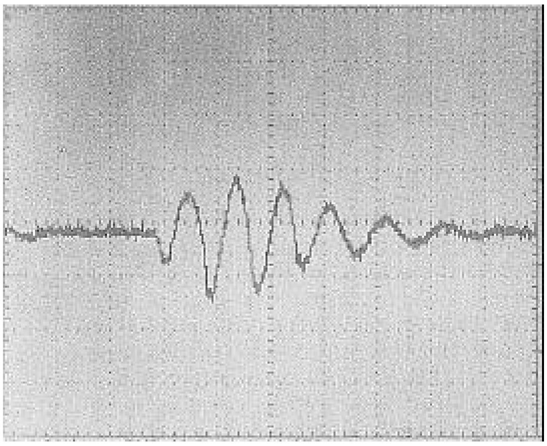


Figure 8: Beam induced voltage in C36 (One-turn delay feedback "Off") with 9×10^{12} protons

The "One-turn delay feedback" [5] has been upgraded to cover the range of harmonics now required. The improvement brought by this system has been indeed observed on the various cavities, and the case of cavity 36 is shown in figure 9 for illustration (to be compared to figure 8 where the feedback is Off). The response is aperiodic, and the 4 bunches can clearly be distinguished, spaced by ~ 200 ns since the beam is held on harmonic 10 at that moment.

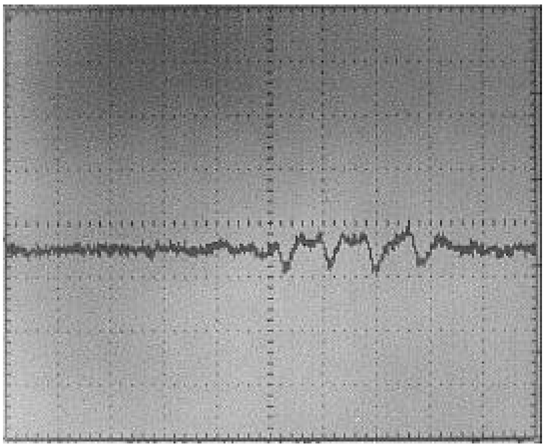
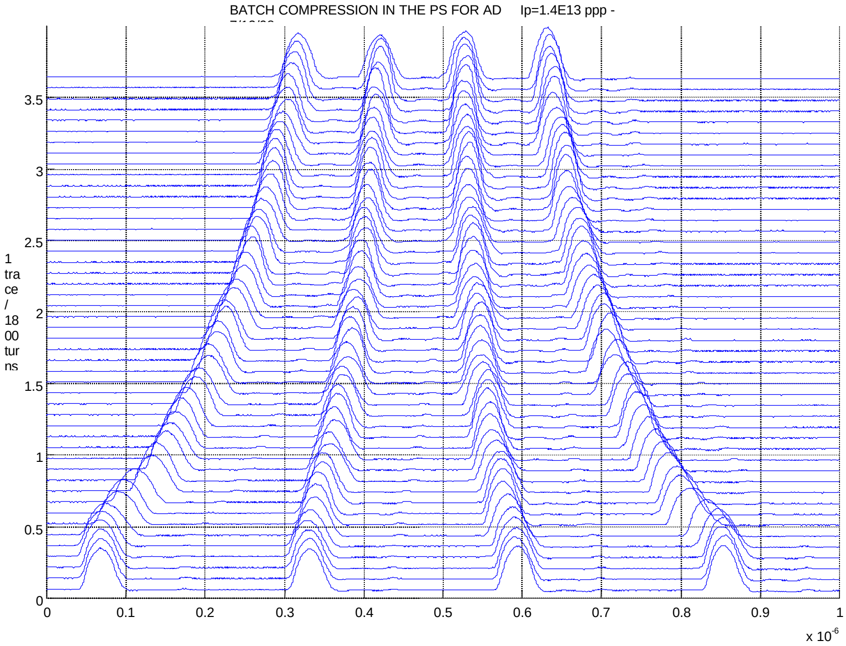


Figure 9: Beam induced voltage in C36 (One-turn delay feedback "On") with 9×10^{12} protons

After fine adjustment of this feedback on all cavities, good results were obtained up to a record intensity of 1.35×10^{13} ppp, without using the gap relays. This is illustrated in figure 10 which shows a mountain range display of a wide band longitudinal PU during the full process. Almost no beam oscillations are visible, which is confirmed by the observation of the bunches at the end of the process, and emittance blow-up is negligible (~ 10 %).



[Trigger C1110]

Figure 10: Mountain range display of beam PU signal (100 ns / div, 1 trace/1800 turns)

3.4 Synchronisation and bunch rotation

A first attempt to synchronize the beam at revolution frequency during the batch compression process did not succeed. More work is required on this subject, starting with thorough checks of the hardware involved.

Bunch rotation has not been tried yet.

4. Conclusion

The setting-up of the anti-proton production beam of the AD has remarkably progressed in 1998. Thanks to the new electronics and to the capabilities of the present controls, the beam control is compact and reasonably easy to diagnose.

During the MD session on the 7th of December, a beam of 1.4×10^{13} protons was accelerated and compressed in ¼ of the PS circumference, while preserving the emittance of the individual bunches. Correct operation of the upgraded “One-turn delay feedback” on the ferrite cavities was critical for this achievement.

Before delivering this beam in operation to the pbar production target, more hardware has to be designed, built and adjusted during MD sessions to settle the following issues:

- beam synchronization at the revolution frequency before ejection, to permit multi-batch filling of the AD,
- bunch rotation,
- adequate excitation of cavity 11 to make it a spare capable to replace any other one.

Considering the fast advancement of the setting-up in 1998, there is every reason to assume that the nominal pbar production beam for the AD will be indeed operational as planned, at the end of summer 1999.

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