THE ANTIPROTON PRODUCTION BEAM FOR THE ANTIPROTON COLLECTOR ("A.C."): BEAM EXPERIMENTS AND RF DEVELOPMENTS

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Introduction and Summary

The CERN Antiproton Collector ("A.C.") imposes stringent requirements on the proton primary beam from the PS (bunch length shorter than 25 ns, and more than $2*10^{12}$ protons per bunch at the production target) [1].

A technique has been proposed which provides that beam by a quasi-adiabatic merging of pairs of bunches [2]. Most of the envisaged RF manipulations have been tested during recent machine experiments. Performance is at present limited by the RF cavity amplifiers. Nevertheless, the most delicate part of the process ("bunch pair merging") was successfully carried out up to an intensity of $3*10^{12}$ protons per bunch after merging. The experience gained from these tests is presented.

Considerable effort went into RF hardware development. The low power part is complete. The design of the high power system is now being finalized and construction is about to start.

Both parts are described in this paper.

High intensity bunches in the CPS

The present maximum intensity per bunch in the PS injector (PSB) is $2*10^{12}$ protons, leading to 10 to 20 percent less at 26 GeV in the PS. Two techniques are under investigation which try to merge protons from 2 PSB bunches into a single one in the PS and theoretically double the PS bunch intensity.

The first one works at injection energy and proceeds by insertion of 2 bunches inside a single PS bucket [3]. It is strongly non adiabatic but has been shown to increase intensity up to $2.2*10^{12}$ protons per bunch, while keeping losses at a reasonable level.

The second one can realize an adiabatic bunch merging at a higher energy, where bucket acceptance is large [2]. This report is centered on this last method.

Adiabatic scheme

10 adjacent bunches are injected from the PSB and captured in 10 PS h=20 buckets. After acceleration to 3.5 GeV, pairs of bunches are merged by slowly changing the harmonic number of the RF voltage from h=20 to h=10. 5 bunches remain which have to be accelerated on h=10 up to maximum energy (26 GeV). Then the RF harmonic number is quasi-adiabatically increased until the 5 bunches reside in adjacent h=20 buckets. That is obtained by repetition of a basic scheme where the voltage on harmonic number h+2 is first increased and, when it is maximum, voltage on harmonic h initially bunching the beam is gently reduced. Figure 1 illustrates that basic process.

Low level RF system (Fig. 2)

In addition to generating the various RF excitations necessary for the beam gymnastics, the low level RF was also designed to:
- minimize transients by limiting the number of switching actions during the cycle;
- reduce the number of adjustments;
- allow voltage reduction by counterphasing and preserve it even when the harmonic number is swept;
- be decoupled from the other RF systems activated on different machine cycles.

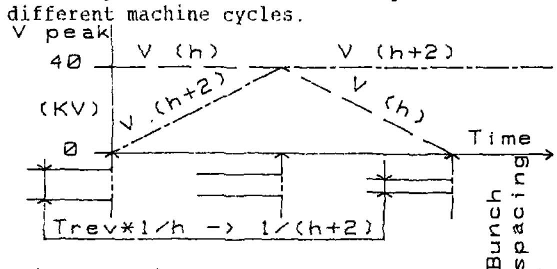

Fig. 1 Basic RF process for batch compression

Digital frequency synthesis

4 direct digital frequency synthesizers (D.F.S.) are used. Their output frequency Fout is:

$$Fout = Fclock * (h/2^{22})$$

with: Fclock = input clock frequency,
h = digital control word.

D.F.S.0 is driven by a crystal oscillator at 2^{24} Hz, and its control word is derived from a real time B field measurement in the bending magnets. After multiplication by 4 it delivers the 32nd harmonic of the central orbit revolution frequency which clocks the 3 other synthesizers.

Their output frequency is given by

$$Fout = Frev*(h/2^{17})$$

which makes it easy to generate any harmonic number, and also to sweep between successive integers only by incrementing low weight bits of the control word "h".

A module called "Digital Loop Processor" drives that control input. In the "Off" status it is transparent to the digital word coming from a "Fast Function Generator"; this is the case during most of the RF gymnastics on flat tops. In the "On" status its output is the sum of the digital word from the FFG, plus a digitally converted analog input signal. It is used to:
- close a phase loop on the beam during acceleration;
- synchronize the D.F.S.'s with respect to each other during the gymnastics.

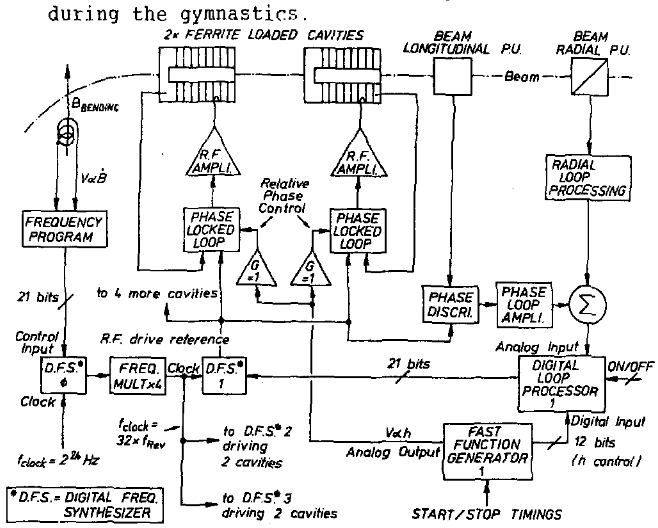

Fig. 2: Simplified block diagram of low level R.F.

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Cavity phasing system

During acceleration periods all 10 cavities are excited by D.F.S. 1. During RF manipulations 4 cavities are stopped, and each D.F.S. drives 2 of the active ones (Fig. 2).

Phase-Locked Loops are inserted in the RF drives to allow precise relative phase control. They measure the phase of a cavity probe signal with respect to their RF input. Any phase shift due to power amplifiers, cavity tune or beam loading is then automatically compensated. A voltage proportional to the harmonic number (FFG analog output) is used for phase control. That takes automatically care of the relative phase within cavity pairs over all the range of harmonics.

Beam control

It acquires the phase difference between beam PU signal and RF excitation and controls the frequency of D.F.S. 1 through D.L.P. 1. A radial loop is incorporated, as well as a "Hereward damping" acting on the accelerating phase.

Experimental results

Many machine experiments were dedicated to the test of this process [4]. Two aims have been pursued:

- setup and adjust the new low level system with low intensity beams;
- realize the most delicate part of the process *(bunches pair merging)* at high intensity to search for any unexpected beam behaviour.

Many hardware improvements were triggered by the first kind of experiments. But the beam manipulation itself has not been tested further than reported in 1985 [2]. The most important lesson is that adjusting the system is time-consuming. Investigations are going on to define the optimum adjustment procedure.

Two sessions were dedicated to high intensity tests [4], and important results were recorded:

- beam-loading compensation is mandatory to handle bunch pair merging even at moderate intensity ($< 10^{13}$ ppp).
- once beam-loading is compensated, successful merging has been obtained at the highest possible beam intensity (Fig. 3 at $1.45*10^{13}$ ppp).

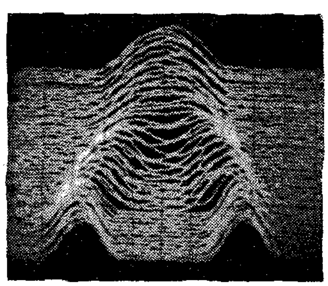

Fig. 3 Bunch pair merging at high intensity

Each merged bunch contains $3*10^{12}$ protons and longitudinal emittance blow-up is around 70 %. Conditions were fulfilled for the subsequent gymnastics, which the experimental setup was unfortunately not able to realize.

Improvement of the high-power RF system

From the very beginning of the project, beam loading was expected to be a major source of trouble. Because of the many harmonic numbers used in the process, a wide-band HF feedback reducing the apparent cavity impedance [5] is the logical choice. It has already been successfully applied to the RF systems of various machines (ISR [6], AA, LEAR, PSB ...). Its basic specifications are in our case:

- frequency range: 2.6 to 10 MHz
- cavity impedance reduction factor: 10 (at resonance).

Because of this wide frequency range, all the amplifying stages included within the HF feedback loop have to be housed in the cavity base.

Radiation

In depth analysis has shown that, after an exposure to 10000 rad near a high energy accelerator, semi-conductor components may display a degraded performance [7]. Confirmation was given by the observed destruction of a 130 W VMOS amplifier after 23000 rad [8]. That precluded the use of semi-conductors in the cavity base, since the radiation dose there exceeds 20000 rad per year of typical PS operation [8].

Amplifier electronic design

A new driver amplifier is implemented, which provides 20 dB open loop gain at the cavity tune frequency (Fig. 4). Two amplification stages are cascaded. They make use of 3 YL1056 (Siemens) tubes, with 2.0 kW plate dissipation capability. Both stages are of the grounded cathode type.

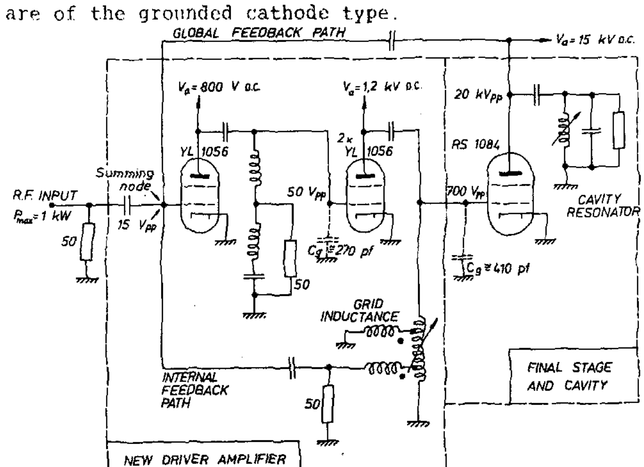

Fig. 4 Simplified schematic of the cavity amplifier

A variable inductance is connected in parallel to the 410 pF of the final tube (Siemens RS 1084) grid to ground capacitance. The driver amplifier can develop up to 700 Vpp across that resonant circuit (Fig. 4). Very small Q values are necessary to preserve loop stability (Q=2 at 10 MHz). That is obtained by the combined action of a 50 ohms damping resistor and of an HF feedback around the driver stages.

Amplifier mechanical design

The new installation has been designed to fit inside the present final amplifier plug-in [9]. Moreover, the final tube is kept in place and only minor mechanical modifications are made. The complete new driver amplifier is inserted as a module in the plug-in (Fig. 5).

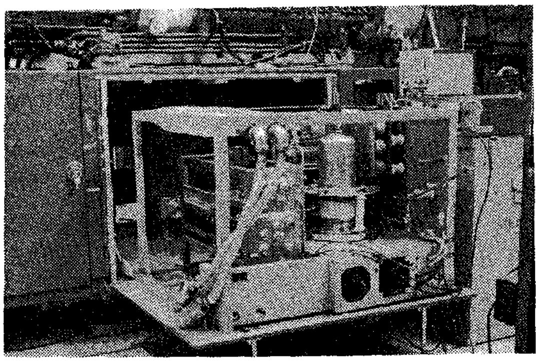

Fig. 5 amplifier plug-in in front of a cavity base

Cavity and amplifier servo systems

Two low-level feedback loops control cavity tune and voltage, and another one makes the final grid resonator track the cavity tune (Fig. 6).

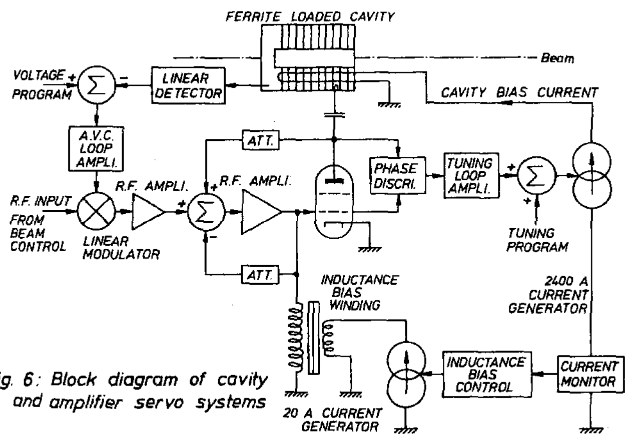

Fig. 6: Block diagram of cavity and amplifier servo systems

The present tuning loop acquires the argument of the impedance of the cavity as seen by the final tube, and acts on the ferrites bias current to minimize tube dissipation. An improved one, measuring the reactive power, will be implemented to insure loop stability under heavy beam loading [10].

The voltage loop acquires the peak gap voltage through a linear detector, and controls the level applied to the cavity amplifiers through a linear modulator. It ensures that the gap voltage follows the computer generated program.

The grid resonator control loop measures the cavity ferrites bias current with Hall effect sensors, and follows an experimentally derived law to generate the corresponding inductance bias current.

Prototype tests

The prototype version of this system (Fig.5) has attained the above mentioned specifications on the test cavity. Measurements of overall gain from RF input to cavity gap are given in Fig. 7. Open loop (continuous line) and closed loop (dashed line) results are shown, at the extremes of the cavity tuning range. 23 dB open loop gain at resonance is obtained at all frequencies, without any degradation of loop stability. The closed loop gain at resonance is constant, and independent of frequency.

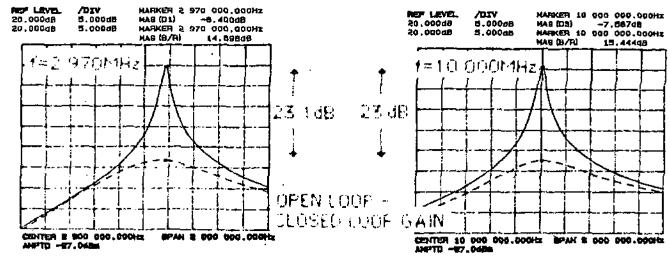

Fig. 7 Transfer function measurements

Conclusion

Substantial progress **has** been made towards providing the AC machine with a production beam making an optimum use of the PS input beam from the PSB. Machine experiments and tests of the new cavity amplifier prototype are very encouraging.

Series construction of 13 amplifier plug-ins has started. For the PS start of February 1988 all cavities have to be equipped. Beam experiments can then proceed. Operational use of the process is expected for autumn 1988.

Acknowledgements

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