ACOL STOCHASTIC COOLING SYSTEMS

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Abstract

The CERN Antiproton Collector cooling systems are designed to reduce the transverse emittances and the momentum spread by one order of magnitude in the duty cycle of the proton synchrotron. Fast cooling is obtained using a 2 GHz bandwidth split into three equal sub-bands. Limitations due to weak input signals and to high output power are overcome by using cryoelectronics techniques and by maintaining the electrodes close to the beam while the beam envelope is shrinking. The characteristics of the main components: mobile electrodes, combiner/splitter structures, preamplifiers, solid state power amplifiers and filters are reviewed. A short description of the new cooling systems in the accumulator ring is also given.

Introduction

CERN is completing the construction of a new antiproton source[1] (ACOL) which is designed to produce ten times more antiprotons per unit of time than the original antiproton accumulator (AA). The gain in particle intensity is essentially due to a major increase, a factor 16, of the source acceptance by the addition of a new ring, the antiproton collector (AC). In the new configuration, the AC acts as a buffer between the production target and the existing AA which is refurbished with upgraded cooling systems. To collect a large number of particles is only half the problem of a powerful source: the particles have still to be "digested" efficiently by an accumulation system whose factor of merit is precisely the particle flux to be handled. For a flux of 4×10^7 particles per second, as it is contemplated for ACOL, the beam received from the target has not, and by far, a density amenable to an immediate accumulation and is therefore submitted to the following manipulations:

i) Just after injection into AC, the short antiproton bunches are elongated with the minimum dilution using the "bunch rotation" technique so that the relative momentum spread is reduced from 6 to 1.5%. The process lasts a small number of turns.

ii) The beam is then compressed from an initial emittance of 200π mm.mrad down to 25π mm.mrad in both horizontal and vertical planes using a novel cooling technique in which the electrodes accompany the beam as it shrinks.

iii) Simultaneously with the transverse cooling or after it, depending on the available electromagnetic power, the momentum cooling takes place during a little more than 2 seconds to confine the beam within 2‰ relative momentum spread.

iv) After rebunching and transfer from AC to AA, the beam is further cooled vertically and in momentum to meet the density requirements compatible with the accumulation process.

The various systems will be described and emphasis will be put on those aspects which had to be developed specifically for ACOL. The high-density core cooling will eventually be the object of a separate paper[2].

General Characteristics

The scaling laws of stochastic accumulation can be derived from an ideal model[3] in which the beam density Ψ increases exponentially with the energy E:

$$\Psi = \Psi_0\, e^{(E-E_0)/E_c} . \quad (1)$$

The subscript "0" is related to the injected beam, E_c is a characteristic energy. Such a density profile is achieved with a gain which decays exponentially with energy; the gain is shaped, in part, at the edge of the pick-up electrodes where the sensitivity σ is:

$$\sigma = \sigma_0\, e^{-\pi x/h} , \quad (2)$$

x is some closed orbit position and h is the half gap between the electrodes. The optimum flux Φ is then given by:

$$\Phi = W/\ln(\Psi_1/\Psi_0) , \quad (3)$$

Ψ_1 being the final density and W the frequency bandwidth. The dominant parameter is W which has been multiplied by 4 in ACOL with respect to the original AA design. As a consequence, the stack width is decreased to avoid the overlap of Schottky bands and so is the electrode gap and hence the beam emittance to maintain the same final density. Furthermore, the initial gain has to be minimized for beam stability reasons and to limit the noise in the high-density region; this gain is determined by the energy spread of the freshly deposited beam which has to be displaced in 2.2 s to leave space for the next pulse. The initial accumulation conditions have been fixed to:

$$\varepsilon = 16\pi \text{ mm.mrad} \qquad \Delta p/p = 5 \times 10^{-4} .$$

They determine the performances to be expected from AC and AA cooling systems whose main characteristics are listed in Tables 1 and 2 and which are implemented according to the layout of Fig. 1.

Table I - *AC cooling systems*

Frequency band [GHz]	1-1.6	1.6-2.4	2.4-3
Cooling systems	H,V,p	H,V,p	H,V,(p)
Nb. of pick-up tanks	2	2	2
Pairs of double loop pick-ups	24	32	48
Electrode size (length × width [mm])	33×46	24×34	16.25×32
Nb. of kicker tanks	2	2	2
Pair of double loop kickers	24	32	48
Nb. of amplifiers/tank	24	16	24
Max. power/amplifier [W]	95	85	55

Table II *AA precooling and accumulation systems*

System	Pre-cool. (V,p)	Accumul. (p)
Frequency band [GHz]	0.8-2.4	0.8-2.4
Nb. of pick-up tanks	2	1
Pairs of single loop pick-ups	96	32
Electrode size (length × width [mm])	39×38	39×38
Nb. of kicker tanks	1	1
Kicker structure	48 pairs of single loops	Travelling wave slot structure
Nb. of amplifiers	4	4
Max. power/amplifier [W]	100	100

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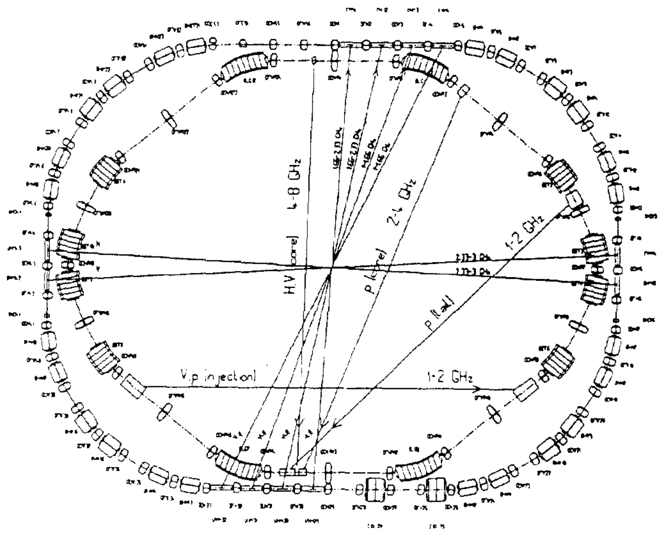

Fig. 1 - Stochastic Systems in ACOL.

The AA systems are based on the classical principles of stochastic cooling[3]. In AC, the transverse cooling is severely limited by the electronic power[4]; the difficulty is overcome by maintaining the electrodes near the beam envelope during the cooling, this way the emittance decays linearly until it is limited by the thermal noise. The total frequency bandwidth is split into three sub-bands inside which the electrode dimensions, the circuits and the amplifiers are optimized.

Signal Processing

The signal processing will be discussed for the AC systems only. The first element in the chain is the electrode which acts like a quarter wave directional coupler. Longitudinally, the electrodes are grouped in pairs (double loops). The connection between the two loops of each pair is made by a half-wavelength long coaxial line so that the peak response is 3 dB higher than the peak power delivered by two single loops. A typical frequency response is shown in Fig. 2 for two extreme values of the electrode position corresponding to the beginning and the end of the cooling. The gain increase is approximately as expected but the phase changes significantly because of coupling between the opposite electrodes and a dynamic phase corrector is being designed to compensate this variation.

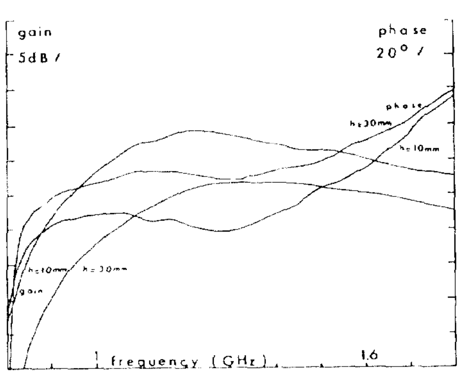

Fig. 2 - Double loop frequency response.

At the electrode output, the signals are first combined in microstrip circuits (Fig. 3) then delayed in coaxial lines and finally added in an impedance transformer which has the shape of a tapered strip line. The signal and load circuits are identical but independent. Two identical sets of structures are located symmetrically with respect to the beam in each tank.

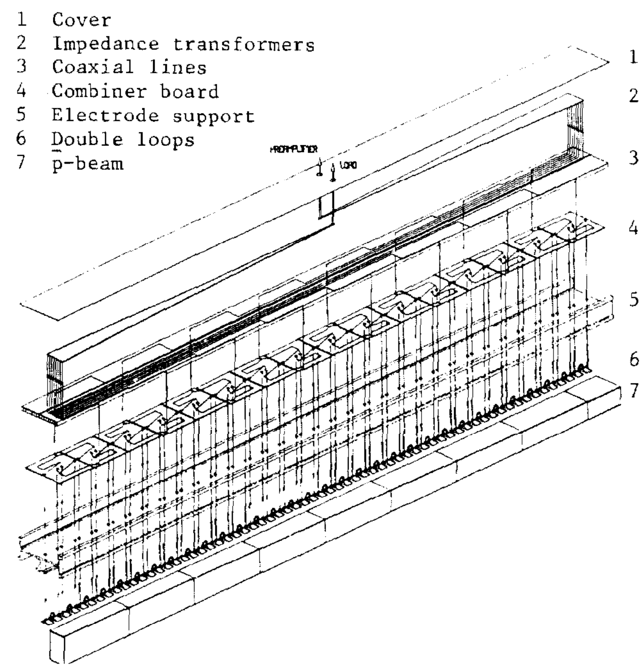

Fig. 3 - Blown-up view of a signal combination structure

The signals coming from the two amplifiers are both added (momentum information) and subtracted (transverse information) in a hybrid circuit. The momentum signal passes through a passive notch filter followed by an active filter which enhances the gain around the notches. The power is kept constant by varying the electronic gain during the cooling.

The total electronic gain is 156 dB. At the pick-up's, the signal level is of the order of 1 picowatt whereas it amounts to several kilowatts in the kickers. All the amplifiers and especially the power amplifiers must have a linear response. Solid state amplifiers have been preferred to travelling wave tubes for their lower intermodulation products, their weak amplitude dependent phase shift and for economical reasons. They have been especially developed for the ACOL project[5]; a typical frequency response at low level and at 1 dB compression is presented in Fig. 4.

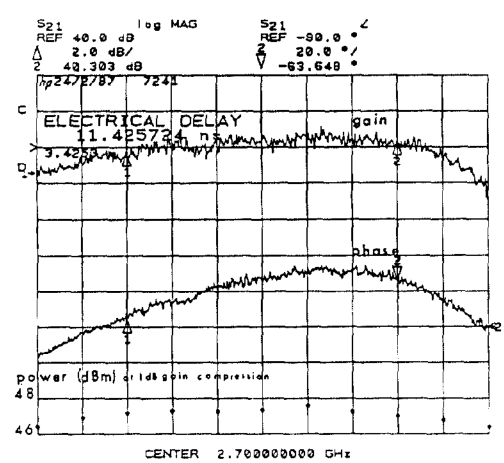

Fig. 4 - Frequency response of a power amplifier.

Mechanical Aspects

The pick-up and kicker stations consist of cylindrical stainless steel high-vacuum tanks. Each tank contains two moving Al alloy electrode supports facing each other inside the tank and two fixed ferrite damper profiles.

The electrode supports are attached to rigid stainless steel actuating shafts which are supported by linear guides mounted on solid frames on the outside of the tank. The vacuum seal between the shaft and the tank is maintained by welded bellows (Fig. 5).

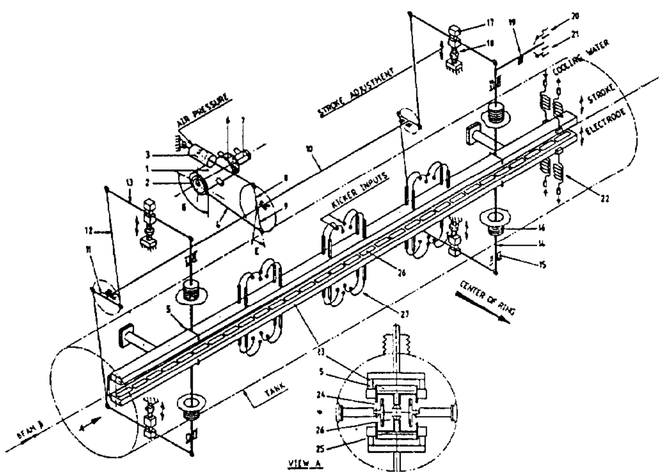

Fig. 5 - *Stochastic cooling kicker kinematics*
1) AC servomotor, 2) eccenderdrive, 3) air compensation cylinder, 4) connecting rod, 5) flexible pivots, 6) integral motor resolver, 7) position resolver, 8) compensating crank, 9) actuating crank, 10) transmission shaft, 11) cranke arm, 12) connecting rod, 13) rocking lever, 14) actuating shart, 15) linear guide, 16) bellow, 17) slot guide, 18) jack, 19) accelerometer, 20) limit switch (out), 21) limit switch (in), 22) spring tubes, 23) electrode support, 24) ferrite support, 25) combiner board, 26) electrode, 27) flexible striplines.

The actuating shafts are moved almost symmetrically using an AC servomotor, an eccentric driver, a transmission shaft and an adjustable lever system. The actuator system is mounted on solid frames outside the tank. A pneumatic cylinder is used to compensate for the pressure exerted on the sealing bellows.

The driving mechanisms for the pick-ups and kickers are identical in design. The stroke, which is different at the upstream and downstream ends of the electrode supports, is adjusted by varying the length of the lever arms, the radius of the crank arms and the slot guide positions. A full stroke of the electrode support, 32 mm (240π) and 23 mm (25π) respectively for the upstream and downstream ends is made by a motor rotation of 180°. The return stroke is made by -180° rotation. The electrode supports follow the cooling in 2.25 s and are retracted in 150 ms

The pick-up tank structures are cooled to 100°K by radiation to a surrounding thermal copper shield. The preamplifiers and the loads are cooled to 20°K by conduction[6].

The kicker tanks and electrode supports are water cooled to dissipate the heat generated by the terminating resistors. The connections are made by flexible stainless tubes.

Kickers

Linear moving mass of 2 electrode supports and linear guides	99.2 kg
Linear equivalent mass of rotative parts: levers, transmission shaft	12 kg
Total fictive mass at the end of motor eccentric	128 kg
Max. stroke	32 mm
Max. acceleration	1.2 g
Symmetry of movement	~ 2%
Tank length	2.2 to 2.3 m
Tank diameter	0.5 m
Total mass of tank equipment	1050 kg

Pick-ups

Linear moving mass of 2 electrode supports and linear guides	84 kg
Linear equivalent mass of rotative parts: levers, transmission shaft	12 kg
Total fictive mass at the end of motor eccentric	118 kg
Max. stroke	32 mm
Max. acceleration	1.2 g
Symmetry of movement	~ 2%
Tank length	2.2 to 2.3 m
Tank diameter	0.5 m
Total mass of tank equipment	1100 kg
2 cryogenerators/tank, first stage	50 W at 80°K
second stage	2.5 W at 18°K

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