A DAMPER FOR THE $\bar{p}$ INJECTION OSCILLATIONS IN THE PS MACHINE.

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Introduction

After accumulation in the AA ring, at 3.5 GeV/c, the antiprotons are injected as a low intensity ($10^9 \div 10^{10}$ ppb), 80 nsec single bunch into the PS machine, accelerated up to 26 GeV/c and then transferred to the SPS collider. Random transverse errors at injection into the PS lead to beam oscillations which increase the transverse emittances and decrease finally the luminosity in the collider. As part of the improvement program for the p$\bar{p}$ run at the end of last year a "damper" has been installed in the PS to counteract such oscillations. This paper describes the justifications, the technical solutions and the results of such an equipment.

Parameters evaluations

From now on we will consider only the horizontal plane but the same considerations and even the same numerical values (in the PS) apply in the vertical plane as well. Let us call ε_f the final beam emittance (after filamentation), then [1]:

$$\varepsilon_f = \varepsilon_i + \varepsilon_a \qquad (1)$$

where
$\varepsilon_f = (2\,\sigma_f)^2/\beta_c$ [π.mm.mrad]
$\varepsilon_i = (2\,\sigma_i)^2/\beta_c$ [π.mm.mrad] : initial beam emittance
$\varepsilon_a = 2x^2/\beta_c$ [π.mm.mrad] : "unwanted" supplement in beam emittance given by a small injection error of amplitude x [mm].
σ_i and σ_f [mm] : initial and final half rms beam width
β_c [m] : average value of the β-function {= 16 m}*

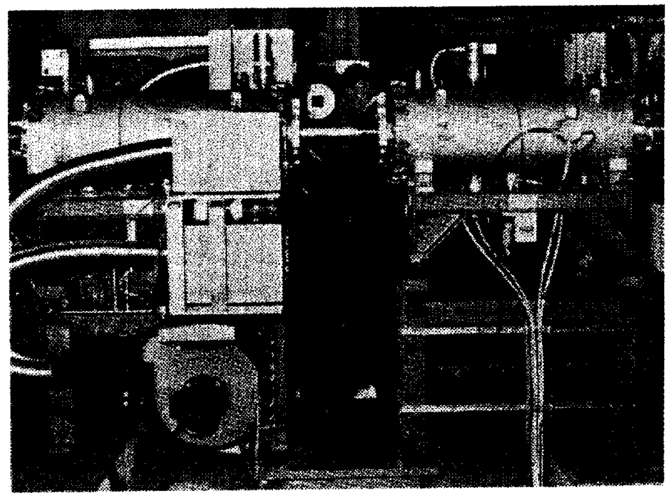
Applying the formula (1) to a beam of ε_i = 2πmm.mrad, an injection error of x_o = 3 mm (... which can be considered as a "bad" injection) leads to an emittance blow-up larger than 50%. To reduce the blow-up to, say, less than 10% one has to damp the original 3 mm oscillation to less than ≈1.2 mm in a time shorter than the filamentation time. This implies a damper gain G defined as [2]:

$$G = \frac{\text{kicker deflection}}{\text{beam position at the p.u.}} = \frac{x'}{x} =$$

$$= \frac{2\,t_r}{\sqrt{\beta_p\beta_k}\,(\sin\varphi)}\ln\frac{x(t_c)}{x_o} \quad [\text{mrad/mm}] \qquad (2)$$

where
t_r : revolution period {≈ 2.2 μsec}
$x(t_c)$: oscillation amplitude for $t = t_c$ {≈ 1.2 mm}
t_c : filamentation time, $t_c = t_r/(\sqrt{2}\,\pi\,\Delta Q)$
$\Delta Q = \xi Q\,\Delta p/p$
ξ : chromaticity {= -1}
Q : tune {= 6.25}
Δp/p : half momentum spread {= $0.6\cdot10^{-3}$}
x_o : injection error {≈ 3 mm}
β_p, β_k : values of the β-function at the p.u. and kicker position {$\beta_p = \beta_k$ = 22 m}
φ : betatron phase advance swept by the beam between the pick-up crossing and the corresponding kicker deflection. As in the PS: Q = 6.25, the same location for the pick-up and the kicker leads to |sin φ| = 1 on every odd number of turns.

*) Numerical values between {} brackets are the specific PS machine values.



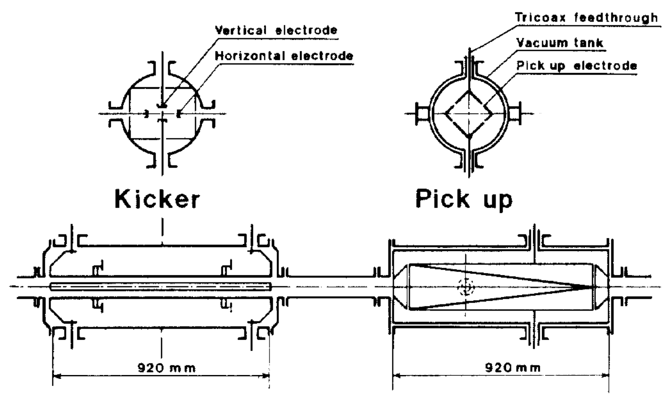


Fig. 1 : Kicker and pick-up as installed in the PS ring

The maximum deflection is of course given by :

$$x'_{max} = G\; x_{max}$$

so if x_{max} ≈ 3 mm then x'_{max} ≈ 5 μrad.

Hardware implementation

The information on the amplitude of the oscillation can be extracted by filtering whatever betatron line within the spectrum of the p.u. signal and normalizing to the beam intensity. For practical reasons we have chosen to filter the lowest one i.e. f_β ≈ .25 f_{rev} ≈ 115 kHz

Pick-up

The very low intensity of the $\bar{p}$ beam requires a high sensitivity pick-up. An electrostatic pick-up with a square cross-section of its electrodes turned by 45 degrees [3, 4] has been chosen. The horizontal and vertical electrode pairs are combined on a length of 720 mm. At each end some space is available to adapt smoothly the square shape of the electrodes to the elliptical vacuum chamber of the PS. These pieces are part of the internal screen which is insulated from the vacuum tank. The electrodes with their screen are located in a vacuum vessel 920 mm long with 350 mm internal diameter (Fig. 1).

The connections to the electrodes are made in the equilibrium point of their surfaces to minimize parasitic resonances. Triaxial vacuum feedthroughs are used for the signal and the internal screen connections. The lowest measured resonance of the electrodes with their vacuum feedthroughs appears above 150 MHz.

The bandwidth of the pick-up with its amplifiers has not only to cover the needs of the damper loop but should also allow the observation of the bunch signal. This pick-up will be used for heavy ion (O^{8+}) acceleration in the PS as well. Therefore each electrode is equipped with a cathode follower which presents a high impedance to the low capacitance (45 pF) electrodes. The housings of the cathode followers are in contact with the vacuum tank whereas their ground is connected to the internal screen. The inputs of the cathode followers are equipped with diode clamping circuits which protect the tubes from the rather high voltages which develop on the electrodes during acceleration of high intensity beams.

Triaxial cables (75 Ω, 5 m long) transmit the output signals of the cathode followers to the difference and sum amplifiers in a remote location to shield their semiconductor components from radiation. The difference amplifiers are conventional long-tail pairs in cascode connection with heavy emitter degradation to obtain a maximum linear dynamic range with good common mode rejection. Due to the high sensitivity of the electrodes the gain is moderate (30 dB) and can be reduced by a factor of ten by switching resistors in the second stage. The sum amplifier consists of a double common base stage presenting a well defined termination to the cathode followers.

For a typical parabolic bunch of 10^9 particles, 80 ns long the pick-up delivers a difference signal of 10 mV/mm with a wide band (DC-100 MHz) signal-to-noise ratio of 8 dB. The sum signal for the same conditions is 70 mV. The overall bandwidth is 20 kHz - 30 MHz (-3dB).

Betatron Oscillation Measurement

Since the difference signals (Δ) from the pick-up amplifier have the bunch shape, the betatron oscillation at 115 kHz is extracted by means of a bandpass filter whose cut-off frequencies are 10 kHz and 200 kHz. The group delay of this filter is 3.5 μs.

A wide band (50 kHz-130 MHz) power amplifier (+29 dBm) with a gain of 26 dB (MINI-CIRCUITS ZHL-32A) is located in front of the bandpass filter in order to avoid noise problems as much as possible.

The input voltage range of this amplifier allows to cover a beam intensity range from 10^9 to $2.5\ 10^{10}$ particles per bunch for an oscillation of not more than ±10 mm.

The amplifier should see a 50 Ω load over its entire frequency range. For this reason it is terminated by 50 Ω in parallel with the 620 Ω characteric impedance of the filter. The matching network introduces a 6 db gain loss.

Any beam with a non-zero average position in the pick-up at injection, even without oscillation, generates a transient signal at the filter output. This unwanted spike lasts about 5 μs and its amplitude is proportional to the beam's position and intensity. To prevent this spike from reaching the kicker, the gate action of the gain control stage is used.

Sum Signal Conditioning

The filtered signal must be normalized to the beam intensity. This is accomplished by peak detection of the sum signal of the pick-up. The intensity and the bunch shape are assumed to stay constant during the damping process.

The peak detector should detect negative and positive signals corresponding to antiproton and proton operation during test periods.

The linearity error of the detector is less than 1.5%. Its output voltage rise time has been limited to 1 μs to match the speed of the denominator input of the Δ/Σ divider. The time constant of the droop is about 0.5 ms.

The input voltage range is 14 mV to 400 mV, which corresponds to beam intensities from 10^9 to $6\ 10^{10}$ particles in 80 ns bunches.

Normalization and Gain Control

Normalization (Δ/Σ) is achieved by an analog divider (ANALOG DEVICES AD 539J). The detected sum signal which constitutes the denominator voltage of the divider is always kept above 0.1 V to avoid division by zero and to guarantee a divider bandwidth of at least 350 kHz.

Since this control voltage should always be

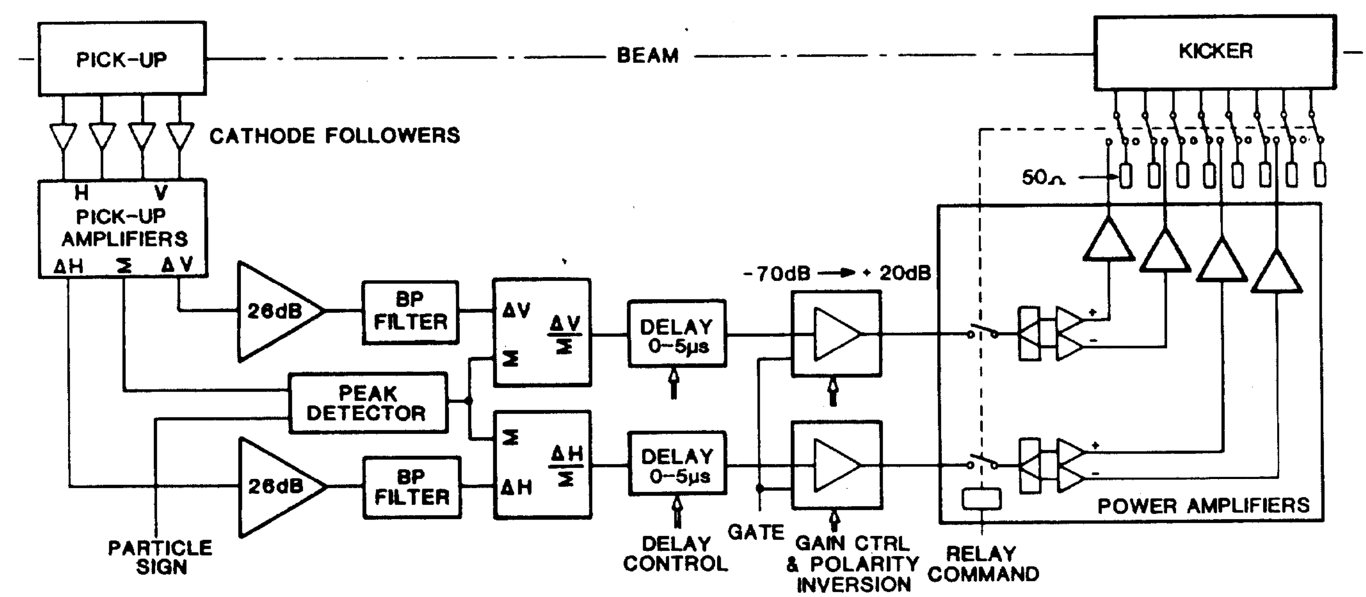


Fig. 2 : Block diagram

positive, the sum signal of the pick-up is inverted at the peak detector's input depending on proton or antiproton operation. In this way the output signal of the divider keeps the polarity correct for the operation of the electrostatic kicker.

The phase of the normalized signal is adjusted by a series of tapped delay-lines, with a 5 μs setting range, and a polarity inverter for an additional step of about 4 μsec.

The total gain of the system can be varied from -70 dB to + 20 dB by a gain controlled amplifier whose control voltage has been digitally linearized. This gain control stage acts also as a linear gate to stop the action of the damper [5].

High Level Electronics

The kicker together with four power amplifiers, solid-state preamplifiers and ancillary circuitry form the high-power part of the system. At the input end, two single-ended correcting signals at a level of ≈5 dBm are delivered by the low-level part. The preamplifier converts them into push-pull form and increases the level to maximum 5 V peak at the 50-ohm matched outputs. Expanded to four channels, the signals are routed via coaxial cables over a distance of about 50 m to the ring.

Each final amplifier is equipped with one air-cooled tetrode YL 1440 (made by Philips), allowing a plate dissipation of 1.5 kW. The tubes are operated in a class-A, grounded cathode configuration; negligible grid current is drawn even under full load. The input is wideband, consisting of two cascoded 2 to 1 step-up transformers, terminated in 800 ohms at the grid. The overall bandwidth is therefore determined by the output circuitry, which is designed to absorb a load capacitance of 110 pF as given by the vertical system. (The capacitance of the horizontal system is lower due to shorter feeder length and wider kicker electrode spacing, but was brought to the same value by the addition of a 10-pF-capacitor). A bandpass configuration with two tuned circuits is used, resulting in a 1-dB frequency range of 40 kHz to 190 kHz together with a delay of 0.92 μsec around the center frequency of 115 kHz. At the nominal output voltage of 2'500 V peak, the termination of 10 kilo-ohms has to dissipate a power of 312.5 W. It is implemented as a string of 14 wirewound resistors, mounted in the air duct to the amplifier valve and cooled by the incoming air stream. A sample of the output signal is taken by a 60 dB resistive divider and brought to the control room via low-loss cables.

The active part of the kicker is formed by two pairs of copper-plated electrodes, 35 mm wide and 900 mm long. Their characteristic impedance in push-pull mode (i.e. single electrode with respect to the virtual ground planes in the beam axis) is 136 ohms for the horizontal and 115 ohms for the vertical plates. Supported by low-capacitance ceramic insulators, the plates are connected to the outside of the vacuum tank by 8 ceramic feedthroughs. During the high-intensity proton cycles, each plate is terminated at both ends by a 50-ohm absorber to minimize the beam-equipment interaction; 8 SPDT vacuum relays switch the plates during antiproton cycles to the amplifiers. An interlock acting on the preamplifiers inhibits the RF in case of inadequate relay status : this should prevent absorber burnout by the amplifiers in case of control errors.

Ease of maintenance was the primary goal in the mechanical design of the final amplifiers. The units are easily handled by a single person; special quick-release connections allow rapid attachment to the output feeder lines.

Ancillary equipment like interlock and power supplies is located in the equipment room and completes the system.

Mechanical Implementation

The vacuum tanks for the kicker and the pick-up are shown in Fig. 1. They are a new standard for short straight sections in the PS.

All parts in the vacuum are cleaned and assembled using techniques which are now conventional for ultra-high vacuum. Stainless steel parts are baked at 950°C and isolations are made with brazed alumina supports.

We have used copper gaskets for the small flanges under 200 mm diameter and aluminium gaskets for the 350 mm diameter.

A small (60 l/sec.) ion pump is mounted on each tank.

Results

To help the setting up and the evaluation of the system a proton beam with the same characteristics as the antiproton beam has been accelerated from 3.5 to 26 GeV/c. The Q-measurement fast kicker has been used to simulate in a controlled manner at 3.5 GeV/c the transverse oscillations. The emittance measurements performed at 26 GeV/c with flying wire scanners and scrapers have shown good agreements with computations through formula (1) and (2). A 3 mm oscillation of a 2 π mm.mrad beam leading to a measured blow-up of 56% without the damper and to a blow-up of 10% with the damper switched on. The same results were observed on the antiproton beam. See Figure (3).

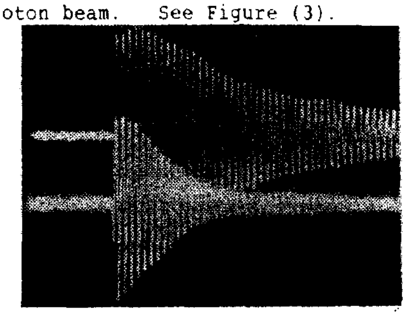


Figure 3 : Upper trace : amplitude versus time of the horizontal betatron line without damper (decay time = filamentation time).

Lower trace : as above, same initial error but with the damper switched on. (50 μsec/div.)

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