I. Introduction

The heart of all proposed Stochastic p accumulators is a "fast" momentum precooling section, whose performance (time to cool $\delta p/p$ by a certain factor) must match the cycle time of the accelerators which supply and empty it of ps and/or the cooling time of a companion stacking section. Here I discuss some inherent design limitations of the fast cooling section and some "ways out".

The usual Fokker-Planck formulation of momentum cooling admits an invariance (ideally, with no circuit noise) such that for cooling by a fixed fraction $F$:

$$T_c = K(F) \frac{N}{2W}$$

(1)

where $T_c$ is the cooling time, $N$ the total number of ps being cooled, and $W$ the effective feedback channel bandwidth. The function $K(F)$ is normalized such that $\Delta K/\Delta F = 1$. This formulation suggests a wide latitude in design possibilities. Precooler circumference does not enter so that it could be a free parameter to satisfy other (than cooling) constraints. The ratio $N/T_c$ is constant so that either large $N$ stacks of ps or many dilute batches of ps could be precooled to give equivalent net yields.

In practice such a wide latitude of design is not possible. Several reasons for this are independent of the cooling itself (e.g. production target heating limitations). However the state of art of filter momentum cooling places some restrictions which exclude desirable designs. In particular, to get by with small precooler rings and/or lessen the target heating problems one would like to cool many dilute p batches sequentially with $T_c$ very small. Unfortunately the signal to noise (S/N) ratio is very small in this case while the broad band power required to lower $T_c$ would be prohibitive. I will discuss a technical approach which avoids this dilemma and, finally, outline scenarios employing the techniques.

II. Cavity Pick Up

The conventional longitudinal pickup or kicker is a beam-wall gap type cavity (or, equivalently, described as a beam transformer) loaded with ferrite to give very low $\omega$ and hence large bandwidth. The beam coupling impedance of such a device must be proportional to its $Q$. This fact necessitates hundreds of such devices ganged; at the P.U. end to achieve good S/N and at the kicker end to reduce the final amplifier power. Technically the intervening electronics (P.U. to kicker) cannot be improved to achieve better S/N or higher power, since these are incompatible with large instantaneous band width (200-500MHz).

Conceptually, one could span the same large $W$ with a P.U. consisting of a large number of higher Q cavities each covering contiguous frequency bands. Indeed, this is feasible under certain conditions,
Where we assume that $G \equiv \omega_0/2Q$, is the same for each cavity (by fabrication). In this case $G \ll \omega_1^{-1}$ so the time domain P.U. signal is essentially given by the bracket; a pulse of width $(2\omega)^{-1}$. In the time domain such a P.U. array is entirely equivalent to the usual P.U. By reciprocity it can be demonstrated that the kicker works as well.

But there is more! The bracket in (4) is periodic with period $2\pi/\omega_0$. To avoid these after pulses:

$$Q_i < \pi \omega / \omega_0$$  \hspace{1cm} (5)

which must be compromised with (2). Also my assumption that $G \equiv \text{const.}$ will finally (high enough $W$) be at odds with (3) since $Q_i$ must grow with frequency. In frequency domain the cavities have an inherent phase shift vs. frequency (and the kicker’s does not cancel the p.u.’s)! Whereas the ideal broadband system does not. In practice the case of bad mixing is usually encountered, so that for any practical $W$ (say <500 MHz), (3) can still be maintained. Unfortunately, one could probably not be able to use such p.u./k to extend practical bandwidths or to work near the good mixing limit (even not using filter cooling; see below).

The conditions on cavity $Q$ can be looked at from the point of view of beam coupling impedance. We would like to know if such an array can be more sensitive than an equivalent length of broadband couplers. In the gridded approximation,

$$z_\varnothing = 486 \Omega \nu Q / c$$  \hspace{1cm} (6)

For $L = 6$ cm at $v = 500$ MHz, $Q = 250$ (see below) $z_\varnothing = 12 - 2k\varnothing$, which is to be compared with $z_\varnothing = (#\text{pickups}) \times (\text{coupling impedance per p.u.})$, or $z_\varnothing$ for usual broadband systems (typically $z_\varnothing = (100-200) \times (10-500) \times 10^{-10} \Omega$). The above $z_\varnothing$ represents 13600 $\Omega/m$, compared to 4200 $\Omega/m$ for the AA precooler p.u.\textsuperscript{5} A relevant sensitivity is relative to the overall circuit electronic noise power. In this consideration lies the particular advantage of the cavity p.u. If $Q = (\text{wall loss resistivity})^{-1}$, the relative Johnson noise from the cavities goes as $Q^{-1}$. Better, the Q could be killed by overcoupling the signal output, in which case good copper cavities would be entirely negligible noise sources. Also, the preamplifiers, one per cavity, are narrow band and can now be of entirely different technology than those available for broadband P.U.s. Simple parametric amplifiers with $\approx 20^\circ\text{K}$ N.F. could be used, with the cavity itself as the input tank.\textsuperscript{5}

The essential advantage of breaking up $w$ into many narrow bands with respect to the kickers is the problem is to supply enough voltage kick/turn to the particles to sustain fast cooling (rms rates $\times 10$ mev/s). Narrow band tube amplifiers can easily supply more power than the reasonable broadband devices now contemplated.

On the other hand a large number of preamps and power amplifiers are needed. For filter cooling the same number of stub lines would also be needed. Fortunately an alternative filterless cooling method is possible.\textsuperscript{5} In fact, this method is ideally suited for use with cavity array p.u./kickers since it works best with a lower noise electronic circuit. This concept in comparison with filter cooling is sketched in Figure 2.

A particular interest at Fermilab for such cooling schemes stems from our accumulator designs requiring a large cooling factor and deceleration to a low energy electron cooler. Under these circumstances it is possible to cool without shrinking the Schottky bands by a large factor. This condition is also best suited to the "transit time" cooling method. This fact is illustrated by Fokker-Planck simulation of both cooling methods for equivalent, realistic feedback circuits (see Figure 3).

It is seen that the rates at early times are comparable but much less cooling is obtained asymptotically with the transit-time circuit (note that the same noise level broadband circuit is operating for both these curves).

III. Application

Besides the advantages of lower noise (or same noise level but shorter p.u. not lengths) and higher attainable power levels, the above scheme (cavity p.u./kickers mated with transit time cooling) allows new accumulation scenarios to be contemplated. Since any complete, consistent scenario requires detailed consideration of many interconnected problems I will suggest only some general outlines.

It would be advantageous to construct a precooler with as small a circumference as bending magnet field allows (for the 8 GeV top energy of Fermilab designs). This would be 1/4 $\times$ 1/3 Booster C.) For noise

\text{\textsuperscript{5}}
insignificant we see from (1) that small rings do not
effect cooling per say. Also, the formula for for
required kicker power:

\[ P_k = N \Delta P_r^2 R' / W_w \]  \( (7) \)

where \( R' \) = instantaneous cooling rate, shows that \( P_k \)
go down with circumference.

The traditional objections to reducing precooler
circumference are 1, that the straight section length
available for PU and kicker is proportionally reduced;
and 2, that a proportionally large number of batches
must be sequentially extracted from the Main Ring.
The latter is really an advantage as far as target
heating is concerned. However, unless the cooling
time per batch can be greatly reduced, such a
sequential approach greatly lengthens the overall MR
cycle time. The cooling technology of Section II
presents a way out of this dilemma.

It is feasible to incorporate smaller precoolers
in two ways. First a given natural batch length
(e.g. 1/13 MR for the Fermilab case) can be shortened
in the proton ring by RF manipulation. Second, the
proton ring can be segmented into more batches (say
1/25 or 1/39 for the Fermilab MR). The cooling per
batch can be in principal faster by a factor equal to
the batch number (213 for Fermilab) since \( N \) is reduced
(see eg. (1)). Thus with no overhead time for
precooler cycling this class of schemes could preserve
net \( \bar{p} \) production yield. On the other hand \( P_k \)
increases with the batch number divided by the
increase in circumference. Both the rate and power
increase can be achieved with the narrow band
approach. The practical limitation comes from the
implied increase in precooler deceleration rate.
Several tentative scenarios have been devised which
require only 1/3 or 1/4 Fermilab booster circumference
precoolers to attain accumulation rates equal to the
best attainable in the conventional full booster
scenarios. An essential additional element in these
sequential scenarios is the use of electron cooling at
relatively high energy (\( \sim 2.0 \) GeV/c \( \bar{p} \) momentum) to
alleviate the deceleration (from 5.4 GeV/c) rate
problem.

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