Performance of Tevatron I Core Stochastic Cooling Systems

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Abstract

The Tev I antiproton Accumulator utilizes three "core" stochastic cooling systems: two identical (H and V) transverse systems; j and a momentum cooling system. All three incorporate similar hardware, working in the 2-4 GHz microwave band. After several commissioning perids those systems are found to work very nearly to the original design specifications. Cooling tests have been performed with ≤21 ma (1.8×10^{11}) antiprotons and ≤26 ma (2.6×10^{11}) proton beams.

Introduction

In addition to the main stacking cooling system,[1] core cooling systems are needed for two reasons. First, the exponentially growing (in momentum orbit) stack tail profile (see Figure 2) must be terminated over a very small momentum so as to avoid stack loss at the well (inner in our case) while utilizing the full aperture. Second, individual antiprotons spend a relatively short time in the Debuncher and stack tail systems so that full cooling, commensurate with the stacking period (> 4 hours) is not realized, especially in the transverse planes. Thus lower gain but high ultimate density core systems can best prepare the accumulated p's for transfer to the FNAL Main Ring. On the other hand, with such long effective cooling times, "noise" perturbations (along with IBS) will limit the asymptotic density.

A schematic, block diagram of the three core cooling system is given in Figure 1. All systems run in the (nominal) 2-4 GHz microwave band using identical hardware for the "out of vacuum" electronics (e.g. TWT's, hybrids, preamps). The pickup/kicker arrays are also essentially identical (see Figure 2) except that the grouping and physical location of loops is necessarily different for the momentum system.

Figure2. Beam tube wall inner face of transverse 2-4GHz pick up loop row. First four PU pockets have loops. Loops absent in next pockets. To the right is a strip-line combiner board with sma transition in lower RH corner and loop connecting pins next to loop pockets.

Since relevant currents in the Accumulator are ~10^3 greater than for the Debuncher, the pickup signal for all core systems is automatically so much larger that special cooled preamplifiers are unnecessary.[1] Standard commercial (MITEQ) 2-4 GHz GaAsFet units are used. Performance parameters are summarized in the following table.

Accumulator Core System Parameters

Frequency range		2-4 GHz
Pickup loop characteristic impedance:	H/V	83Ω
	Δp/p	108Ω
Beam gap		~3 cm
Loop plate length		2.4 cm
Pickup resistor temperature	Δp/p	80°K
	H,V	300°K
Number of loop pairs	Δp/p	2x16
	H,V each	8
Pickup/kicker sensitivity d(0,0)		1.59
Preamp noise temperature		170°K
TWT's - each system		1

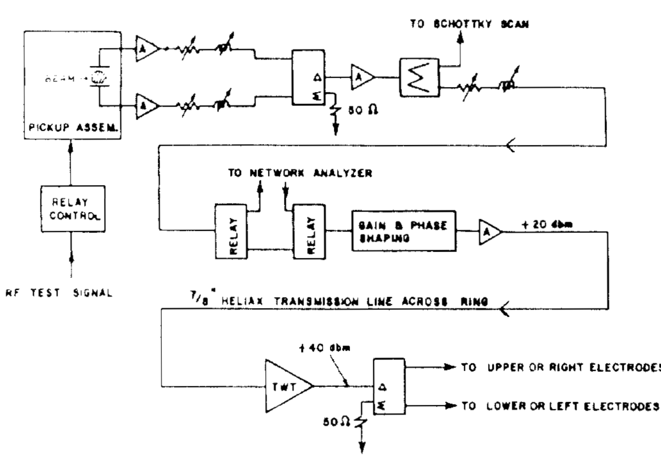

Figure 1
2-4 GHz Core Betatron Cooling System (2 Systems Required)

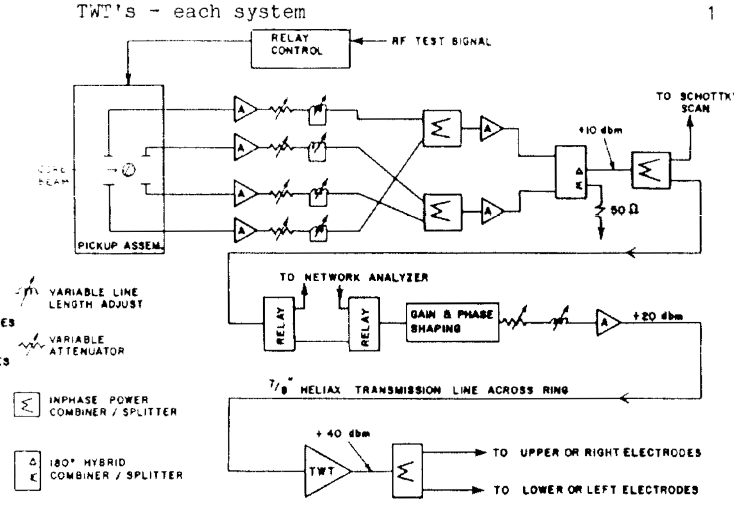

Figure 1, 2-4 GHz Core Momentum Cooling System

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Transverse Systems

Each transverse system consists of identical pickup and kicker arrays. Each array contains 8 odd mode loop pairs (opposed across the beam).[2] This grouping of 8 is the same as employed for fast cooling in the Debuncher. Stripline combiner boards in vaccuo, sum the coherent half signals. These sumed signals (top/bottom or left/right) are transmitted from the stripline to vacuum wall via special "open" 50Ω coax. With some difficulty we were able to make such arrays appear matched to back injected 50Ω signals, with return loss at least 13 db across the band. The transitions: between loop plate and coax; between coax and stripline; and stripline to coax again were the sources of mismatch.

For production uniformity the pu's contained the same ≈100Ω, 10W, terminating resistors which functioned as loads in the kickers.

The H and V pickup arrays are located at the center of the A10 (zero dispersion) long straight section.[2] The difference signal is formed and amplified near the PU tanks and subsequently piped straight across the ring, via air coax, to kickers in the center of the adjacent (A30) long straight where the TWT's were located. TWT's are 200W saturated power units identical to those in the Debuncher.

Momentum System

The Δp/p core kicker at (A30) contains twice as many loop pairs as the H/V system's. The PU works according to the "Palmer Method".[3] Therefore it is located in a dispersive straight (A60). A well defined core momentum is defined by subtracting the sum signals (even mode) from two parallel groups of 16 loop pairs each. These two groups are separated by 60 MeV/c (8 cm, spatially) as shown in Figure 3. The in vacuuo signal combination is slightly different in that groups of four loops are stripline combined. Secondary stripline combiner boards are then used to combine group of four signals.

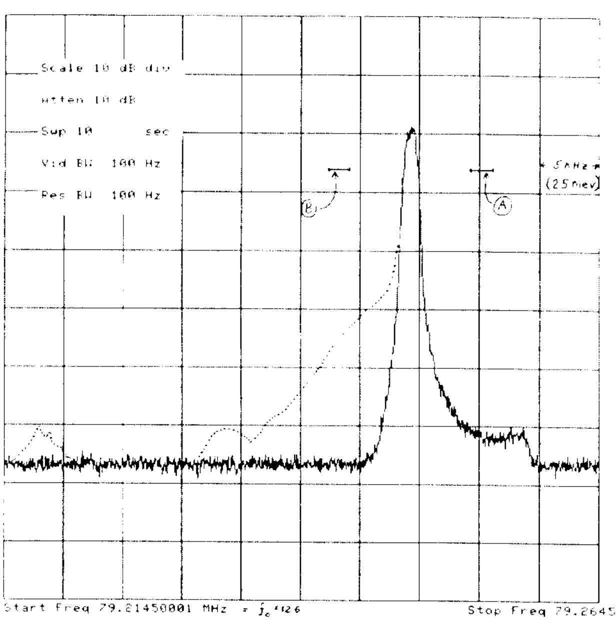

Figure 3. Spectrum analyser trace of CORE momentum distribution in preparation for transfer to TEVETRON. A andB represent the two momentum cooling loop rows. Dotted curve shows full profile during accumulation. Shoulder at right is aperture limit.

Since all core signals are applied to the beam at zero dispersion, they influence all stack tail particles. However the phase is in general wrong for cooling (H/V) or contains no coherent part (Δp/p). This presents no problem for the rapidly diffusing tail particles, but requires switching core systems off for aperture diagnostic studies.

Operational History

The core systems were first installed in the Accumulator in 1985. The commissioning proceeded sufficiently to achieve several ma. cores for Tev I p̄-p collisions in October 1985. During this period and subsequent proton diagnostic runs in early 1986 salient problems were investigated. The Δp/p system was reworked to optimize the null closed orbit. Transverse heating of the core by imperfect effective electrical alignment of the stack tail kickers with respect to the closed orbit was identified as a principle limitation to core current. This represented a heating of the core in direct competition with the H/V cooling, the tail kickers being at zero dispersion. Provision was made to adjust stack tail kicker tank tilt and to diagnose this heating. Finally an automated system to measure cooling system transfer functions was developed.[4]

Commissioning with these improved features commenced in September 1986. Stack cores of up to 21 ma p̄'s and 26 ma p's have been accumulated (design ≈50ma).[4] For >25 ma (2.5×10^{11}) p̄'s we have approached within a factor two of the design peak core density (6.2×10^{10}/ev-s), with transverse emittances better than design ($2\pi\times2\pi$ μm).

Performance

Ideally the Δp/p system centers the core midway between its PU rows (75 MeV/c lower momentum with respect to stacking orbit[2]). A null signal is expected from this center orbit. Figure 4a illustrates the actual results. The degree of signal suppression (gain) we practically run with is also shown. Figure 4b reveals the actual null by scanning in momentum with a probe beam.

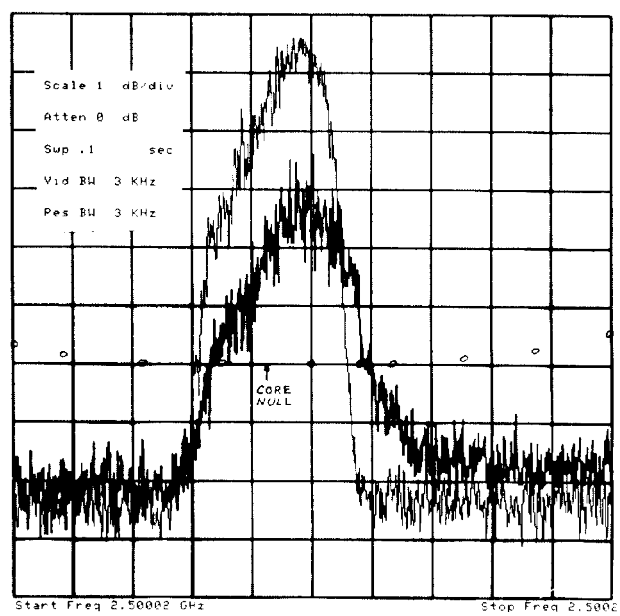

Figure 4. 3976th harmonic Schottky band for 17.3 ma. Light trace: CORE cooling off. Dark trace: cooling on. Position of CORE PU sensitivity null determined by probe beam relative signal (open circles).

Phasing of the $\Delta p/p$ system signal has proven critical. The network analyzer transfer function measurements for this purpose are the same as for all our other systems.[1,4] In setting the net electronic delay a compromise is reached between optimal core profile cooling force and proper "matching" to the stack tail flux. It is observed that the peak core density we achieve is essentially independent of current, for currents($\approx$2 ma) giving significantly greater than unity S/N. Presumably this is connected with the smearing of the expected PU null. Extrapolating this trend we will arrive at just the design core density (6.2×10^{10}/ev-s) at design current.

Although design transverse emittances have been achieved we also measure directly the transverse cooling rates via Schottky scan evolution. At large S/N levels (>10 ma) these rates approach within a factor of three of the simple model estimate $\tau_{\perp}=W/NM$ (M=mixing factor=10.7). Figure 5 illustrates the S/N of transverse signals and typical Physics run signal suppression (gain).

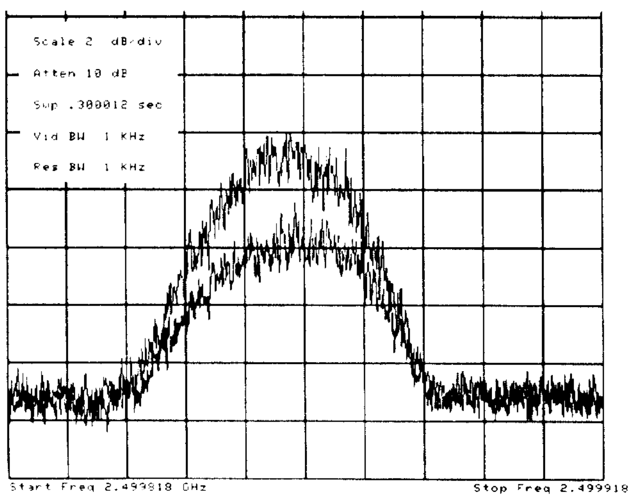

Figure 5. An upper horizontal sideband Schottky signal. Top trace: CORE cooling off. Lower trace: cooling on. Circulating current is 17.3 ma.

Typical core conditions (stack tail off) just previous to a transfer to the Tevatron are illustrated in Figure 6. Under such conditions beam lifetimes >300 hrs. have been observed, consistant with observed single scattering loss rates of ~100 μA/hr and mean ring pressure $\sim1.5\times10^{-10}$ Torr. Studies of the accumulation rate indicate attrition from the core which increases with stack current. At present this is a substantial effect at 20 ma,[4] amounting to ~15% of our input rate (~800 μA/hr). Apparently this is caused by a residual transverse heating from stacktail kicker misalignment. Increasing core transverse emittance as a function of stored current (tail on) is also observed.

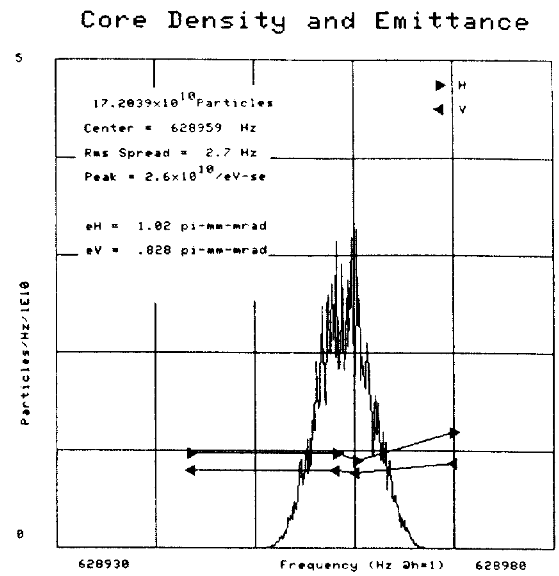

Figure 6. Plots of CORE momentum density and transverse emittance as a function of revolution frequency. Special program calculates these from spectrum analyser Schottky scans.

References

1. R.J. Pasquinelli, et al. These proceedings and D. Peterson et al. ibid.

2. Design Report: Tevatron I Project, September 1984.

3. D. Mohl, "Stochastic Cooling", CERN/PS/DL 78-25, October 1978.

4. J. Marriner, et al, these proceedings.