DESIGN AND PERFORMANCE OF THE AAC STACK CORE COOLING SYSTEM

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Abstract

The object of the ACOL project was higher antiproton stacking rates and integrated collider luminosities, through the addition of a new AC collector ring with bunch rotation and stochastic precooling, and by major changes to the stochastic cooling systems of the existing AA machine. These included the installation of a new 2-4 GHz momentum cooling system and 4-8 GHz transverse cooling systems for the stack core. We describe here the design and performance of the new stack core slotted-pick-up and kicker structures, including the UHV feedthroughs, and the special problems of the old 1-2 GHz kicker, which became the new stack tail kicker, with stringent requirements of symmetry and common mode rejection. The amplifier chains and the methods of diagnostics and measurements are reviewed, and performances are described in terms of beam transfer functions, cooling times and ultimate transverse emittances.

System Requirements and Constraints

The ACOL project required circulating stack intensities of 10^{12} p in the AA, with emittances of less than 9 mm.mrad in both vertical and horizontal planes, in order to achieve the desired luminosity of 4.4 \cdot 10^{30} particles per cm^2 per second in the pp collision regions of the SPS. Time constants of the transverse stochastic cooling systems were to be such that the stack emittances reached this figure during stacking, or very soon after stacking ceased, and while the transfer from the AA stack to the PS and SPS was being prepared. The choice of the 4 GHz octave bandwidth for the new transverse cooling systems made time constants of 15 minutes feasible at circulating beam intensities of 10^{12}, with 1.5 minutes at 10^{11}

The longitudinal stack cooling would have to pull particles delivered by the stack tail system into the stack, and to cool eventually the 10^{12} p to a width of 0.15% momentum, corresponding to the longitudinal emittance of 3 eVs required by the SPS accelerating system. The aim of the AC machine complex can be expressed as a final longitudinal density of 3 \cdot 10^{18} particles/ns reached in 5 hours. The new longitudinal system works from 2 to 4 GHz.

The practical realities require that the cooling systems would also have to cope with sources of beam heating such as neutralization phenomena, non-linear resonances, extraction disturbances, accidental blow-up from dampers, intra-beam scattering, etc.

The constraints to be observed in the design were:

1) the apertures of the 4-8 GHz structures had to be variable to allow the old AA 100m beam to pass without loss during the year of trial running from 1985 to 1986, before the main conversion shut-down from 1986 to 1987;

2) the structure designs had to meet the ultra-high-vacuum requirements of surviving bakeout to 200°C;

3) a high degree of mechanical and electrical symmetry about the beam axis was required of the structures, particularly the 4-8 GHz PU, in order to minimize the common mode signals; this reduces unnecessarily loading of the power amplifiers, and reduces also the incoherent effect of the revolution harmonic on sidebands at higher frequencies, where overlapping of the signals is greater;

4) a low common mode level was also important in the former 1-2 GHz kicker which was to be used as the stack tail kicker from 0.9-2.4 GHz (as well as continuing as the stack core kicker for the 1-2 GHz systems in a back-up role). With 100 or so watts fed into the kicker in sum mode for the stack tail function, there was the risk of unbalance deflections blowing up the transverse sidebands of the core as the stack tail particle frequencies passed through them on their way to the core frequency. The rejection figure aimed at was -34 dB to keep emittance growth below 1 mm.mrad per hour by this process.

5) in the AA-ACOL layout there were more regions where leaking electromagnetic fields could cause crosstalk problems than in the original AA, there being planned some 18 stochastic cooling systems in all, against 7 in the AA, and great care had to be taken to avoid propagation along the inside of beam chambers, and to block unwanted transmission in and out through vacuum pumps, TV viewing ports, and from power amplifiers and cable connectors, and inadequately screened low frequency cables and components.

Structures

Slotted structures, in which the beam is coupled to a coaxial line by a series of transverse slots, have a lower sensitivity than say striplines or loops, but where sensitivity is not the main consideration the slots can offer simplicity and a high precision, which is determined mainly by the machining of the slots in a steel sheet.

The slot dimensions have to be chosen with some care; when the slot dimension at right angles to the beam direction approaches too closely a half-wavelength at a given frequency, the loss of power by radiation into the beam chamber increases rapidly. The increasing of either slot dimension, or closer spacing of the slots, increases the loading of the coupling line by periodic discontinuities, which decrease the propagation velocity along the line. When this is too far below the particle velocity in the beam chamber, there is a loss in the sensitivity or efficiency, and in bandwidth. However, once a good compromise has been found at one frequency, it is a matter of scaling the slots with wavelength for another frequency.

The calculated efficiency of the 1-2 GHz slot kicker was equivalent to 3 eV of particle energy gain per volt applied to a 1:1 500 transformer, in the sum configuration. The same structure as a sum pick-up was equivalent to a coupling impedance of 650. To a first approximation these values remain unaltered by wavelength scaling.

The smaller dimensions for the 2-4 and 4-8 GHz bands, and the variable aperture requirement, demanded a different approach to the mechanical design. For the kickers it was convenient to dispose the slotted electrodes as four separate bars on motor driven guides, this assembly being surrounded by a ferrite tile shielding screen. It was confirmed experimentally that the dominant propagation mode between the ends of the
The pick-up electrodes were arranged two above and two below the beam inside a ferrite shielding screen in the 4-8 GHz case, whereas for the 2-4 GHz Pu they were implanted in movable parallel conducting planes, which were smoothly tapered to and secured to the chamber wall and ceiling by flexible conducting sheets.

There were two main mechanical and microwave design problems, particularly for the 4-8 GHz band. The first was the development of low reflection UHV-compatible feedthroughs, and the second was the design of the coupling line, which had to include sliding contact joints for assembly and for flexibility during bakeout, without introducing reflections, and which had to be mechanically supported by dielectrics, also without reflection.

The effect of reflections from feedthroughs, joints and dielectric supports is most destructive in a pick-up "difference" mode, where any unequal rf properties of electrodes are differenced along with the signals. The measured reflection variations with frequency can at worst be very irregular, with peaks and deep dips, producing an irregular transmission loss with frequency, and irregular and unwanted common mode signals at the revolution harmonic frequencies.

During the construction period, adequate rf performance became available commercially in UHV feedthroughs, but these arrived late and were not adaptable to the structure without extensive modifications. By then the problem of wetting the ceramic/metal interface of a stepped alumina insulator had been largely overcome in collaboration with industry, and reproducible, low reflection performance followed.

The low reflection dielectric supports used for the coaxial inner conductor and the flat coupling line were crossed alumina pins for the 4-8 GHz structures, and polyimide discs (Vespel SP-1) for the 2-4 GHz structures, and for the 1-2 GHz reconstruction.

Laboratory measurements on the structures were carried out by time domain reflectometry and with network analysers, one of which also offered, very conveniently, time domain reflectometry by synthesis. This included frequency response within gated time, and therefore distance, intervals. Figure 1 below shows the transmission plot, on a 1 dB per division scale, of the 4-8 GHz kicker structure as installed in the machine.

Fig. 1 - 4-8 GHz K transmission.

The common mode rejection for one plane of a structure could be measured with the network analyser by collecting the vector information from transmission along two opposite electrodes, and taking the difference between their sum and their difference plots. In the case of the former 1-2 GHz stack core kicker, which had to be modified to work up to 2.4 GHz, the common mode rejection was vulnerable to loose coupling to resonances via rf contacts, particularly at higher frequencies. However, it had been decided for other reasons to install only the lower band stack tail system from 0.9 to 1.6 GHz, and over this band the performance was acceptable (Fig. 2). Distortion of the coupling line flat central conductors during bakeout required their replacement over Easter 1988, and the slot dimensions were increased at the same time in order to increase the kicker efficiency.

Fig. 2 - Stack Tail K Balance.

Electronics and Controls

The stack core cooling systems require electronic gains of the order of 100 to 120 dB, and care has to be taken to prevent microwave leakage from high level to low level points. Circuit noise is not a crucial factor because of the relatively high signals, and adequate amplifiers are commercially available, with noise factors near 3, for the 4-8 GHz band.

The three stack core systems each contain three 40 dB GasFet amplifiers, and a 20 W TWT power amplifier connected by a few metres of foam cable to the kickers. The main transmission line across the accelerator hall is 12 mm diameter foam cable for the 4-8 GHz signals and 40 mm diameter copper line for the 2-4 GHz signals. The 40 mm lines were sufficiently accurate dimensionally for the first higher coaxial mode not to be a problem.

The high level electronics and switching are grouped at the kicker end, connected with copper semi-rigid cable with SMA connectors. As a precaution against rf leakage, the low voltage dc leads to the solid state amplifiers are wound through small ferrite toroids, and the isolation of the foam cables is supplemented by an outer aluminium bellows-type sheath. Microwave shielding slabs, of loaded plastic foam in plastic bags, are kept on hand for dealing with unexpected leakages.

Computer-controlled switching is used to route data and test signals to and from a network analyser, for measurements of beam transfer functions and system electronic gain in any of the three planes. The switching also directs the Schottky signals from the amplified pick-ups, or power spectra from the kickers, to the spectrum analyser. The switching can be controlled from touch panels or via programs, to select a switching disposition for a manual measurement, or in some cases, to carry out a measurement automatically.

System Performance

Currently, in early May 1988, at stack intensities around 2 x 10^13, the horizontal stack core system cools to emittances of less than 2 x mm.mrad during stacking, and around 1 x during cool-down, and the vertical system is less than 1 x in both states. In March
1988, the emittances at \(0.9 \times 10^{11}\) were very similar in both planes, and quite low, as shown below in the tabulated results from the stack emittance measurement. The cooling time constants then were in the range 11-14 minutes. The current stack width at \(2 \times 10^{11}\) is 0.45% in momentum.

![Stack Times and Emittances Table](image)

The present difference between horizontal and vertical performance does not seem to be associated with the different levels of revolution harmonic amplitude across the band, since these common mode signals are generally higher in the vertical system, which is nevertheless working better. Secondly, the beam transfer functions for both planes do not show any marked differences, and the insertion of phase correctors in both systems has not had much effect. It seems more likely that the horizontal system is suffering from heating by hardware coupling within the system, and by coupling to sources outside the cooling system - for example the transverse cooling can be quite sensitive to machine tune.

Fig. 3 below shows a full-band BTF for the horizontal plane, at a beam intensity of \(1.1 \times 10^{11}\) p, with the amplitude trace above and the phase below. Interference is visible around 4.8 GHz.

![Fig. 3 - BTF H](image)

With stack intensity increases in the future we could expect some increase in the momentum width, and more overlapping of the common mode signal with sidebands, and thus increased heating. Beam trim adjustments in the region of the 4-8 GHz pick-up can be used to reduce the common mode average values, but at a cost to the AA acceptance, and a preferred solution if this overlap heating became a limitation would be to move the pick-up tank transversely by a few millimetres.

The 2-4 GHz longitudinal cooling system is adequate for operation at these intensities, but there are some aspects to the system's behaviour which are not well understood. And which seem to be related to the narrower momentum spread obtained with the increase from 1-2 to 2-4 GHz bandwidth. Originally we observed a small satellite stack on the high momentum, low frequency side of the nominal stack centre. This was apparently due to particles grouping around another frequency with correct delay, outboard of the pick-up electrodes on the injection orbit side. This could be removed by unbalancing slightly the line lengths to the hybrids on one side, but then one had problems with very steep particle density gradients with frequency, with instabilities seen on the Schottky signal. It is also suspected that the mixing from the pick-up to the kicker is contributing to a critical phase slip between particles of extreme momenta at the higher harmonic numbers, and one will have to find the best working conditions empirically until the processes become better understood.

The 1-2 GHz longitudinal cooling system was of some use at the start-up, but it became evident that continuing with supplementary 1-2 GHz cooling was likely to add more complexity than would be justified by results, and it was not recommissioned after the winter 1988 shut-down.

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**References**

