

EXPERIMENTS WITH STOCHASTIC COOLING IN THE ISR

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Summary

Recent results with stochastic cooling of vertical betatron oscillations in the frequency ranges 1-2 GHz and 80-360 MHz are presented. The new experimental set-up for cooling of momentum spread in the 50-180 MHz range for low intensities is also described.

Cooling of Vertical Betatron Oscillations

Introduction

Stochastic cooling of vertical betatron oscillations was first proposed by S. Van der Meer.¹ H.G. Hereward extended the theory and took into account a general system gain (the correction per turn) $g \leq 1$ as well as the influence of a finite signal-to-noise ratio $1/\eta$.^{2,3} For a system with constant g over the bandwidth W , the cooling rate for N particles is

$$\frac{1}{\tau} = \frac{W}{2N} (2g - g^2(1+\eta))$$

In order to apply this principle to the ISR, its feasibility was studied⁴ and an experimental system provided first evidence for stochastic cooling.⁵ Practical experience gave rise to the development of the 1-2 GHz system described in the next section.^{9,10}

Since then there has been a growing interest in cooling of low-intensity beams.^{6,8} Cooling time constants of the order of 1 h were found to be possible at ISR energies with a system in the range of 100-300 MHz.⁷ This led to the construction of the 80-360 MHz system described below.⁹ Later it was found that the 1-2 GHz system could give similar results.

1-2 GHz System

The lack in performance of the loop-type pick-up (PU) and kicker (K) used in the first experimental system^{4,5} (insufficient common mode rejection, sensitivity against waveguide modes and restricted bandwidth) was overcome by a distributed PU and K structure (Fig. 1). Coupling with the beam is provided by

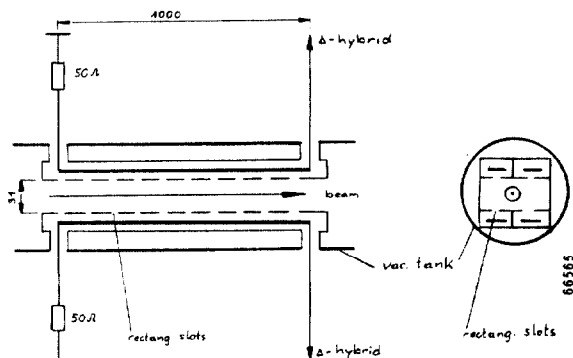


Fig. 1. Distributed PU (or K) structure, microwave system. Connexions shown apply to PU operation.

an array of 30 rectangular slots. Waves propagating synchronously with the beam interfere constructively, whereas waveguide modes cancel. The PU-amplitude response is proportional to f , whereas the kicker action is frequency-independent.¹⁰ Both devices are useful over the band 1-4 GHz; however the presently-available amplifiers restrict the range to 1-2 GHz. The power applied to the K is 1 W. PU and K are subdivided into identical left and right halves to treat the corresponding halves of the beam separately, but only one half is used up to now. Close tolerances assure a high common mode rejection (Figs. 2a, 2b and 2c).

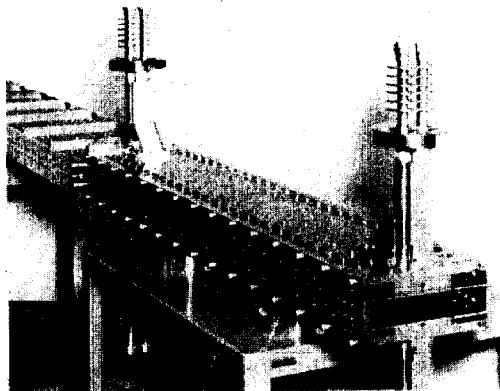


Fig. 2a. General view of the distributed PU (or K); vacuum feedthroughs mounted.

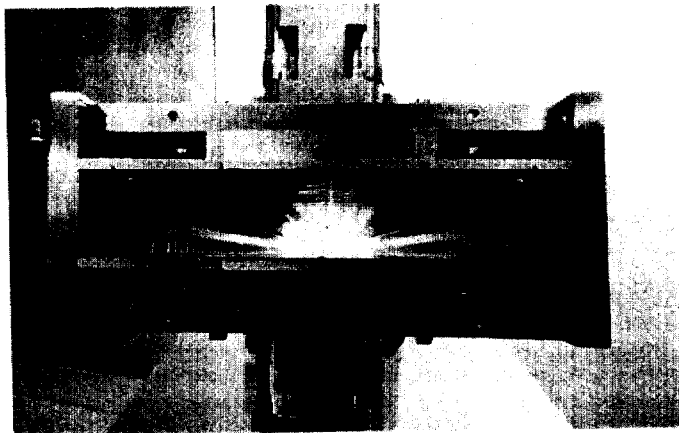


Fig. 2b. The beam chamber of the distributed PU (or K).

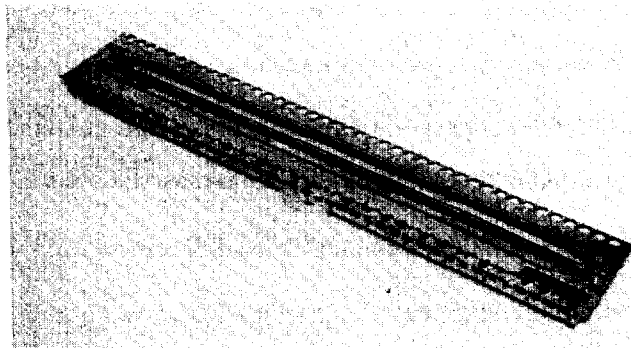


Fig. 2c. One half of the distributed PU (or K) without slot mask.

H.G. Hereward has shown (private communication) that, with the present positions of PU and K, and with standard ISR working lines, the applied kick is about 90° off-phase. A special working line, developed by C. Wyss, now provides the proper phase shift.

Experiments carried out with this system include both medium- and low-intensity cooling.

A 2.2 A beam (26.6 GeV/c) was cooled with an average rate of 2%/h.¹¹ In this experiment, the damping of the betatron oscillations was observed by luminosity measurements.⁵

In the case of low-intensity stacks, the decrease in effective height is monitored by observing vertical Schottky signals. At 26.6 GeV/c a 10.5 mA beam was cooled by about 6%/h. As long as $g \ll g_{opt} = 1/\eta$,⁷ the cooling time constant should scale linearly with momentum. In good agreement with this rule, a 6.4 mA beam was cooled by 14%/h (average) at 11.7 GeV/c. Fig. 3 shows the steady decrease of oscillation amplitude; one line corresponds to one sweep across the vertical Schottky signal at 80 MHz.

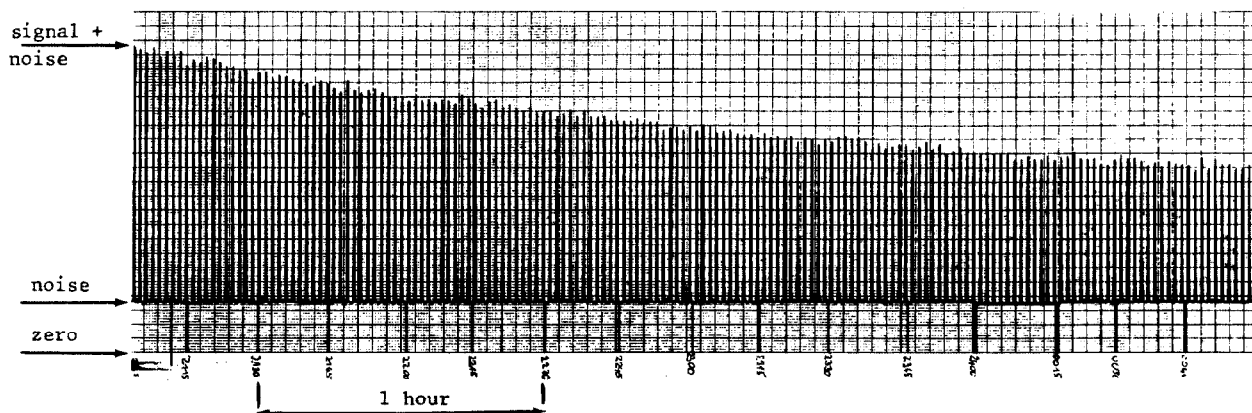


Fig. 3. Decrease of the vertical Schottky signal amplitude of a cooled 6.4 mA beam (11.7 GeV/c).

It is seen from Fig. 3 that the cooling rate changes with time (first hour: 21%/h, last hour: 10%/h). A similar behaviour was observed during earlier experiments,¹¹ but is not yet understood. However, the average rates agree fairly well with theory.¹⁰

Originally, this system was designed for medium-intensity work, aiming mainly at large bandwidths. Increasing the kicker power to 10 W and the coupling with the beam by a factor of 3 for both PU and K would restrict the operating band to 1-2 GHz but, in turn, would offer the possibility of cooling about 25 times faster at low currents.

80-360 MHz System

PU and K for this system, both of the loop type (Fig. 4), have been designed according to the concept outlined in ref. 7 for low-intensity cooling, i.e. concentrating primarily on high coupling. Loops exhibit a $\sin x$ -amplitude response if operated as a PU and a $(\sin x)/x$ -response as a K (first zero at 440 MHz, $x = 2\pi\ell f/c$). The PU is short-circuited at the far end in order to feed the amplifier from a purely reactive (noise-free) source. PU and K positions have been chosen so that the particles complete almost one turn before the correction is applied. The K power applied is 0.8 W, which is about the optimum in the case of

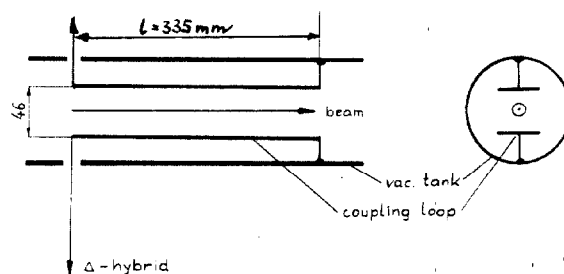


Fig. 4. Loop-type PU for the 80-360 MHz system; the K has the same dimensions, but is terminated with 50Ω at the far end.

11 GeV/c. For 26.6 GeV/c the power can be increased by a factor of 5, yielding an improvement of $\sqrt{5}$ in cooling rate.

The cooling rate is measured as outlined above. However, it is not possible to observe the Schottky signals within the system bandwidth permanently,

because under the instantaneous action of the feedback system, and due to incomplete mixing, these signals almost disappear as soon as the loop is closed. (This indicates that incomplete mixing represents a serious handicap for the low-frequency system in the ISR.) Practically, the loop is open during measurements.

At 26.6 GeV/c a 5 mA beam was cooled by 22%/h. With a different gain and at 11.7 GeV/c an average cooling rate of 59%/h has been observed with a 750 μ A beam over a period of 1 h.

Fig. 5 gives the vertical Schottky signal before the loop was closed and after 30 minutes of cooling. The cooling rate during the first interval was 71%/h.

Improved Cooling of Momentum Spread in the ISR

A first primitive feedback system has been tested in the ISR⁹ using a method suggested by R. Palmer from BNL. A radial difference pick-up observes the error in radial position of the centre of gravity of a short sample with respect to a nominal radial position. The error is interpreted as an error in momentum with respect to a nominal momentum. A fraction g of the momentum error is corrected when the sample passes a wideband accelerating/decelerating gap.

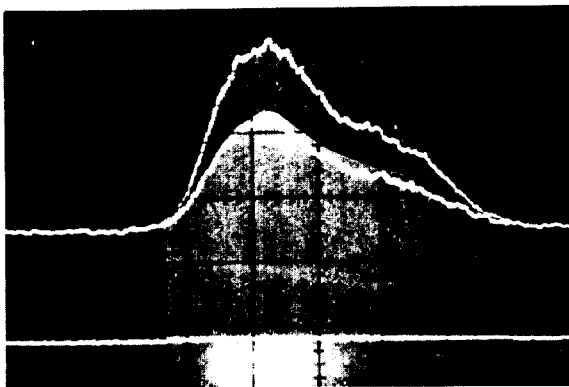


Fig. 5. Vertical Schottky signal before and after 30 min of cooling.

Cooling of horizontal betatron motion should take place at about half the rate of momentum cooling.¹²

Simultaneous stacking and cooling are obtained with the pick-up configuration of Fig. 6. Particles

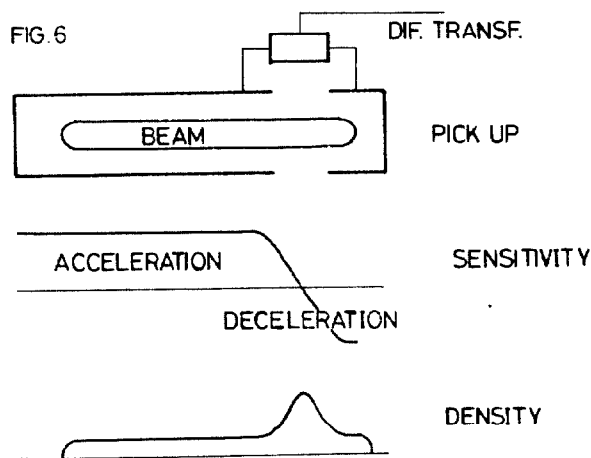


Fig. 6. Stacking in momentum and cooling with a radial difference PU.

deposited inside the large electrode will couple strongly to the system and be accelerated. Particles between the two electrodes will converge towards the nominal momentum.

With $W = 130$ MHz and four pairs of electrodes the induced peak voltage inside the large electrode is $\sqrt{8}$ eWR. With a 3 dB noise figure of the preamplifier and 1 kW total power on four accelerating/decelerating gaps, the single particle inside the large electrode should accelerate with ~ 200 MeV/h. At 30 GeV/c a momentum interval $\Delta p/p$ of 2% should be liberated every three hours to accept new beam.

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