STOCHASTIC MOMENTUM COOLING OF A 7 MeV PROTON BEAM AT TARN

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Abstract

Experiment on stochastic cooling is in progress at TARN, which is an accumulator ring of ion beams from the INS SF cyclotron. The cooling with notch filter method is applied to a 7 MeV proton beam to damp its momentum spread, which is as large as 1 % in full width as a result of rf stacking. The system bandwidth is 20 - 70 or 100 MHz, and the number of particles is $\sim 10^8$. The cooling process is investigated by tuning the system gain and signal delay time. A final rms momentum spread of 0.1 % has been attained by 1 or 2 minute long cooling.

Introduction

Stochastic cooling is an established technique today through vigorous development at CERN. They demonstrated its feasibility to an antiproton source by successful application to a high energy $p\bar{p}$ collider (SPS) and the Low Energy Antiproton Ring (LEAR).1) Stochastic cooling at TARN was proposed to study its feasibility to a low energy beam of 7 MeV/u. The goal was set at momentum cooling of a rf-stacked beam with the notch filter method.2) Prior to the experiment, we investigated certain difficulties proper to TARN, since the lattice of this ring is optimized for multiturn injection and rf stacking of the beam from the INS SF cyclotron, but not for stochastic cooling. The difficulties are 1) a large dispersion function of 1.3 m at the kicker, which causes emittance blow-up due to momentum correction, 2) a large frequency dispersion $((\Delta f/f)/(\Delta p/p))$ of 0.705, which causes Schottky band overlap at lower frequencies, *e.g.* at 160 MHz for a momentum spread of 1 % in full width, and limits the bandwidth of the feedback system including a notch filter, 3) a short beam life time, 440 s at 1×10^{-10} Torr, due to multiple Coulomb scattering of the beam with the residual gas. These problems and the beam instability owing to coherent modulation of the momentum correction turned out not so severe that the stochastic cooling is feasible at TARN.3)

The first cooling was successfully done in February, 1984, and a series of experiments to study performance of the cooling system, *e.g.* cooling time vs system gain and bandwidth, optimization of the notch filter *etc.*, are in progress. The data analysis is also going on. This paper describes the equipment of the cooling system briefly, and preliminary results of the cooling experiment.

Feedback System

A feedback system including a notch filter is designed to attain a maximum gain of 121 dB. The maximum system bandwidth is about 130 MHz, which is limited by the frequency characteristics of the pickup. This maximum bandwidth is wide enough, because Schottky band overlap occurs around this frequency. At the cooling experiment, the bandwidth is defined by a 20 MHz highpass filter and a lowpass filter. Several lowpass filters of various cutoff frequencies are prepared to investigate the cooling process by changing the system bandwidth. The notch filter is an end-shorted 120 m long Hitachi HF-39D coaxial cable. The resonant frequency of the notch filter with this cable is 1.1458 MHz. This frequency is finely tuned by adding a short cable. By adding a end-opened identical cable, we can improve the depth of a notch. The comparison with the single notch filter (the end-shorted cable only) is one of the subjects of the cooling experiment. The block diagram of the feedback system from the pickup down to the kicker is shown in Fig. 1. More detailed descriptions are presented elsewhere.4,5)

The pickup and the kicker are identical 75.5 cm long traveling wave couplers with an inner conductor of helix. The structure is optimized to gain a high coupling impedance at the frequency range of 10 - 100 MHz with conditions required by TARN; equal signal velocity to the beam velocity ($v/c = 0.12$), and a wider aperture than the beam size. At the design, characteristic values of the electrode are calculated with sheath helix model assuming a coaxial structrue. The electrodes are fabricated to be rectangular in cross section as shown in Fig. 2 to match a horizontally wide rf-stacked beam. The detailed description on the the electrode is given in elsewhere.5)

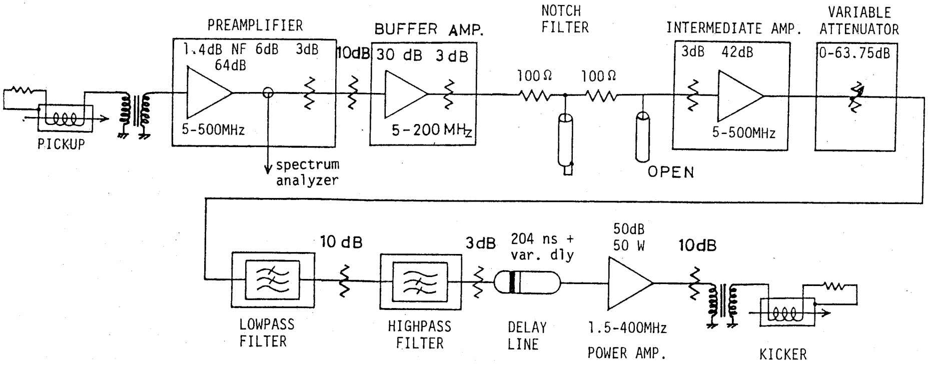

Fig. 1. Block diagram of the feedback system from the pickup down to the kicker.

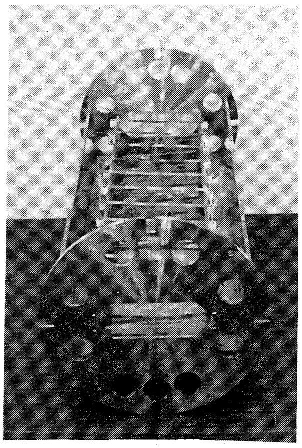

Fig. 2. Pickup/kicker electrode.

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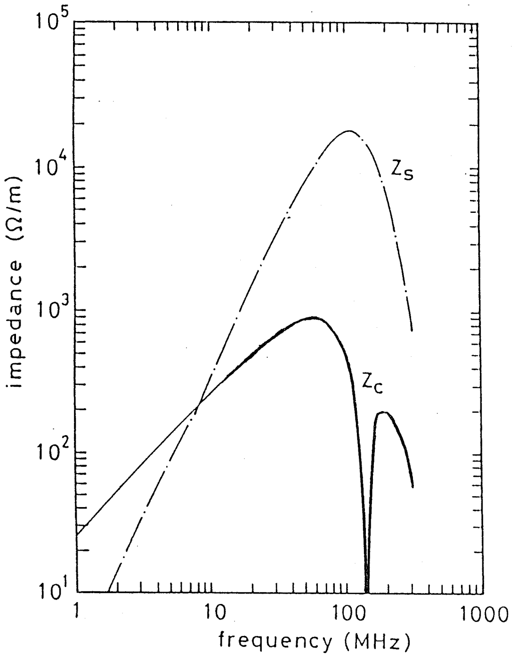

Fig. 3. Calculated pickup coupling impedance (Z_c) and kicker shunt impedance (Z_s) vs frequency. The calculation is based on sheath helix model assuming an coaxial structure.

Measured characteristic impedance of the electrode is about 100 Ω, so the pickup and the kicker are matched to the electronics system with 100Ω/50Ω transformers. The calculated coupling impedance of the pickup and the shunt impedance of the kicker are shown in Fig. 3. Both of them are sufficiently high in the concerned frequency range of <130 MHz. The frequency characteristic of the coupling impedance agrees with measured values derived from Schottky signal power.

Experimental Results of Cooling Experiment

As mentioned above, experiments to study the performance of the cooling system and to improve it are still going on. The subjects are dependence of cooling time and final momentum spread on system bandwidth and gain, and optimization of the notch filter. As the data analysis has not been completed, some preliminary results are presented here.

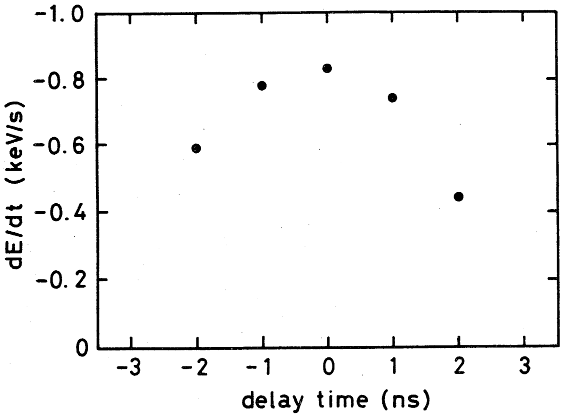

Fig. 4. Acceleration rate versus delay time of the beam signal, by removing the notch filter from the feedback line. The acceleration rate is -0.7 meV/turn with well adjusted delay time with accuracy of ±1 ns.

Timing Adjustment

The transmission time of the beam signal and the time-of-flight of a particle from the pickup to the kicker must be equal. For this timing adjustment, the notch filter is removed. Then the particle is accelerated by its own signal provided the transmission time is well adjusted. The acceleration rate is measured as a funciton of a delay time by tuning the variable delay. Figure 4 shows a typical example of the acceleration rate. The maximum acceleration rate is about -1 meV per turn. According to this result, the transmission time must be adjusted with accuracy of ±1 ns. This value is reasonalble, since the width of one particle's signal is about 10 ns with the system bandwidth of 20 - 100 MHz.

Time Evolution of Momentum Spread

Fiugure 5 shows Schottky scans of the 79th, 80th and 81st harmonics taken at 0, 15 and 150 s. The signal is proportional to particle density (dN/df). The notch filter is the single one. The bandwidth is 20 - 70 MHz, and the variable attenuator and the delay are set at 25 dB and 10 ns, respectively. The initial momentum spread is 0.77 % (FWHM), and the final one is 0.15 %. The initial number of particles is 6.6×10^7, which decreases to 4.3×10^7 after 100 s.

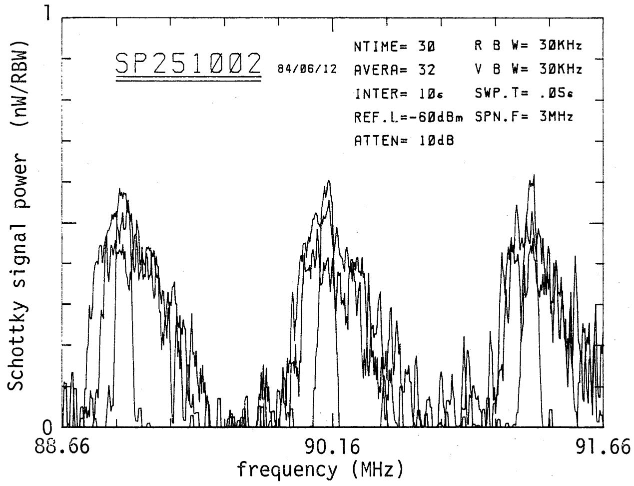

Fig. 5. Schottky scans of 79th, 80th and 81st harmonics taken at 0, 15 and 150 s. The notch filter is single. The number of protons and the system bandwidth are 6.6×10^7 and 20 - 70 MHz, respectively.

Momentum Spread vs System Gain

Figure 6 shows rms momentum spread as a function of time for various values of system gain. In this case, about 1×10^8 protons are cooled by a 20 - 100 MHz feedback system of the single notch filter, and the variable delay is set at 3 ns. The momentum spread decreases exponentially at first and holds at a final value. The experimental result shows that the cooling rate is high with a high gain (a small value of the variable attenuator), and that a small final value is available with a reduced gain, as expected from theory.

The e-folding cooling time is plotted in Fig. 7 as a function of the value of the variable attenuator for various delay times. For 0, 1 and 2 ns, cooling times do not change with delay time, but those for 3 ns are longer. This tendency is consistent with the above result of acceleration rate vs delay time.

Figure 8 shows the survival rate of particles after 300 s long cooling as a function of system gain. The survival rate is dependent on system gain below 25 dB of the variable attenuator. The beam loss might be

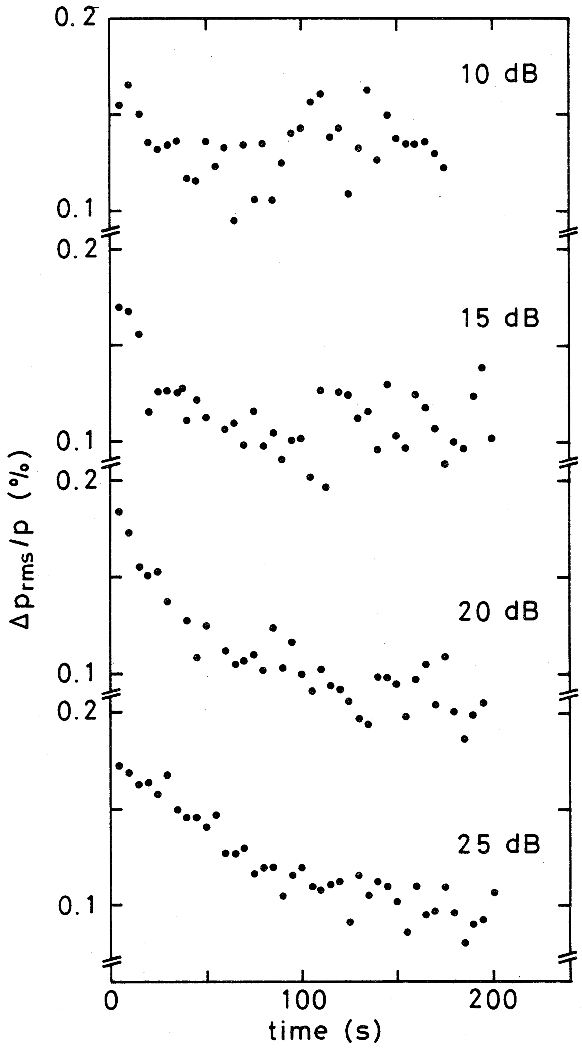

Fig. 6. Root-mean-square of momentum spread as a function of time for values of the variable attenuator.

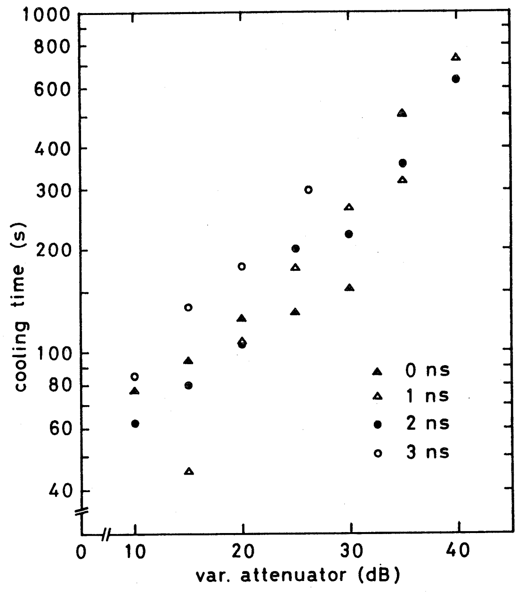

Fig. 7. Cooling time versus the value of the attenuator for various delay times.

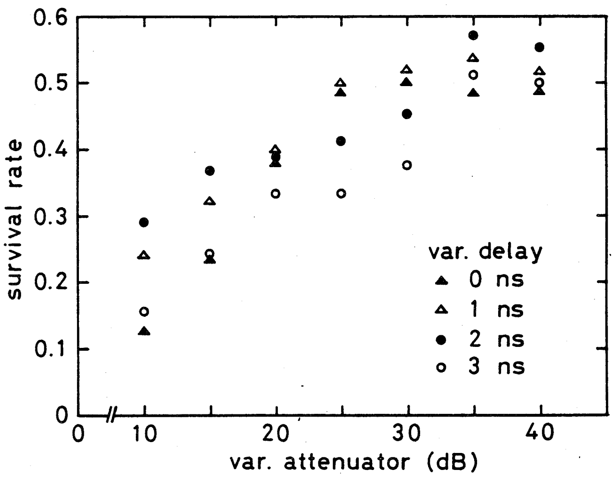

Fig. 8. Dependence of survival rate of particles at the end of 300 s long cooling on system gain.

attributed to the emittance blow-up due to momentum correction at the kicker installed in a straight section of 1.3 m dispersion function. On the other hand, the survival rate is almost constant at a full value of 0.5 with reduced system gain. This value is consistent with a beam loss rate due to the multiple Coulomb scattering mentioned above.

Further data analysis is going on to discuss about the results of the cooling experiment more quantitatively, and to improve the feedback system to attain a shorter cooling time and a smaller final momentum spread. With this success of the cooling of such a low energy beam, we expect that stochastic cooling is applicable to ion beams in an energy region of nuclear physics, and this application is planned at TARN II.$^{6)}$

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