STOCHASTIC MOMENTUM COOLING EXPERIMENTS WITH A BARRIER BUCKET CAVITY AND INTERNAL TARGETS AT COSY-JUELICH IN PREPARATION FOR HESR AT FAIR

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Abstract

Bunched beam Filter momentum cooling has been investigated at the cooler synchrotron COSY. The cooling results of bunching with harmonic number one are compared with those found when the beam is confined in the barriers of a Barrier Bucket (BB) cavity. A momentum cooling experiment at COSY to compensate the large mean energy loss induced by an internal pellet target similar to that being used by the PANDA experiment at the HESR with a BB cavity is presented. A brief comparison with theoretical predictions is carried out.

INTRODUCTION

Detailed theoretical cooling studies have been performed in order to fulfil the requirements for the PANDA internal experiment at the High-Energy Storage Ring (HESR) [1] of the future International Facility for Antiproton and Ion Research (FAIR) at the GSI in Darmstadt. A Fokker-Planck model and a particle tracking code for Filter [2] and the time-of-flight (TOF) [3] momentum cooling method including the signal transfer from pickup to kicker have been developed and applied to predict the momentum cooling performance. A barrier bucket cavity has been included in the model to compensate the mean energy loss due to the beam-target interaction. In a series of experiments the Fokker Planck code including the beam-target interaction has been experimentally verified at the cooler synchrotron COSY [4]. It could be shown that TOF cooling has a larger cooling acceptance as compared to Filter cooling [4]. TOF cooling was found to be very effective to cool the momentum spread prior to Filter cooling. In this contribution the results of further bunched beam cooling experiments are presented. The filter cooling method is applied when the beam is subject to an rf-field of an h = 1 cavity or a BB cavity [5]. The influence of the bunching factor is investigated. In this contribution mainly the experimental outcomes are presented. A detailed cooling model description and a supplemental benchmarking with experimental results at COSY are outlined in [6].

MOMENTUM COOLING EXPERIMENTS

At COSY momentum as well as transverse cooling is available. The system consists of two bands. Band I covers the frequency range (1 – 1.8) GHz and band II the range (1.8 – 3) GHz. The pickup and kicker electrode bars are movable to achieve a maximum in sensitivity. In these experiments only momentum cooling in band II is considered. The proton beam was accelerated to 2.6 GeV/c. To avoid transition crossing during acceleration the optics in the arcs is manipulated so that the transition energy is shifted upwards. At flat top momentum the acceleration rf-cavity is switched off and the optics is changed again so that the machine is now operated above transition energy. By this both straight sections of COSY in which the electron cooler and the pellet target of the WASA installation are located attain zero dispersion. A flat top time of about 500 s was chosen and the particle number was about 1 to 2 $\cdot 10^9$.

Filter Cooling with Barrier or h = 1 Cavity

Experiments have been carried out to investigate the capability of the cooling system to cool the beam into the stable bucket of the h = 1 or BB cavity. The h = 1 cavity was operated at 90 V peak voltage and the barrier peak voltage was 175 V giving the nearly equal bucket area of 1.2 eVs. The beam was adiabatically re-bunched in flat top. The cooling system was operated at the same gain after bunching. The initial momentum spread of the beam was heated by applying band-limited white noise at harmonic number one with a momentum kicker. Therefore only about 30% of the particles are in the stable bucket initially. The nearly rectangular beam distribution was then cooled. Power spectra at harmonic number 1000 were recorded every 30 s during the cooling process, the first spectrum is taken 3 s after cooling start. The rms relative momentum spread was deduced from the measured spectra during cooling as shown in Fig. 1.

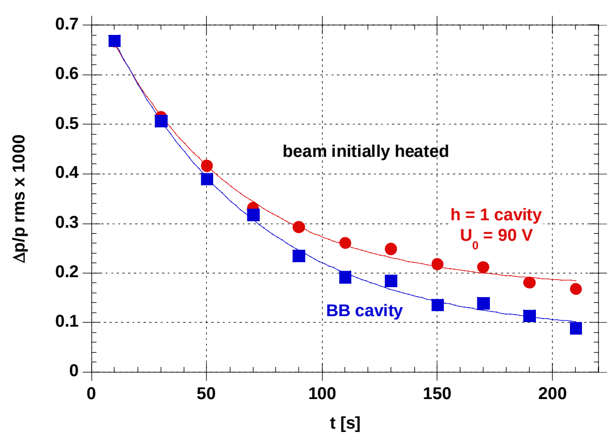

Figure 1: Rms relative momentum spread during cooling.

The measured revolution frequency 1.536969 MHz corresponding to a revolution period $T_0 = 0.65\mu s$ and the frequency slip factor $\eta = 1/\gamma^2 - 1/\gamma_{tr}^2 = -0.065$ have been used. The figure shows that cooling is faster with BB operation. After 210 s the momentum spread is about a factor of two smaller than for cooling with bunching in the rf-field of the h = 1 cavity. This becomes also clear from the measured bunch shape for both cases as shown in Fig. 2 and 3. The bunch length is decreasing while the peak bunch value is increasing as shown for the bunched beam in Fig 2. On contrary, the barrier bucket is continuously filled while the bunch length remains unchanged ($T_B \approx 0.65\mu s$) during cooling.

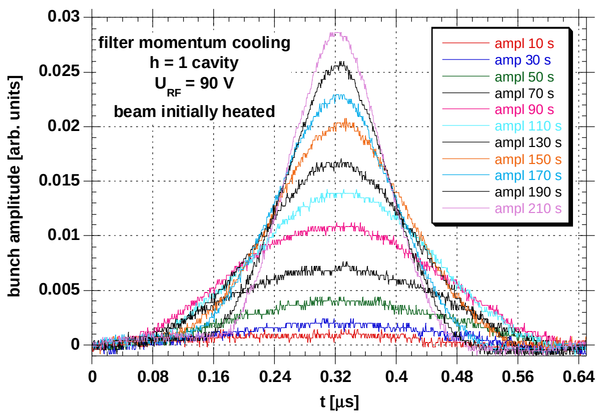

Figure 2: Bunch shape during Filter cooling with bunching in the rf-field of the h = 1 cavity at U_0 = 90 V.

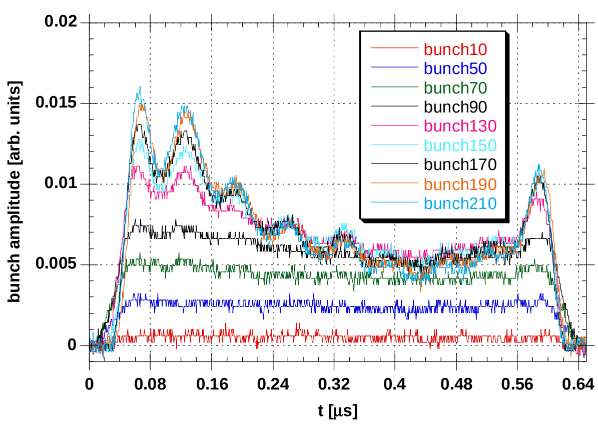

Figure 3: Bunch shape during Filter cooling with BB cavity operation.

Below t = 90 s the beam is nearly DC. Later the bunch shape becomes modulated with an enhancement and a significant peak structure around 0.1 µs. This effect is due to a ripple on the barrier voltage which leads to potential holes in which the particles become frozen when cooling proceeds. A strong correlation signal is then visible in the power spectra. The measurements demonstrate that cooling becomes slower, Fig. 1, when bunching proceeds in the rf-field of the h = 1 cavity, Fig 2.

Filter Cooling for Different Bunching Factors

In a series of experiments the influence of the bunching factor on momentum cooling has been studied. The beam was initially not heated. The momentum spread at t = 10 s is about a factor of four smaller. Cooling has been investigated for the peak voltages U_0 = 90 V, 177 V, 260 V and 360 V of the h = 1 cavity. The cavity voltages were determined from a synchrotron frequency measurement. The lowest voltage provides a bucket area of 1.22 eVs which covers more than 90% of the beam initially. More than 98% of the particles are in the bucket area 2.5 eVs for U_0 = 360 V. For each voltage the power spectra at harmonic number 1000 as well as the bunch shape were recorded every 30 s during cooling. Power spectra for the cavity voltage 360 V are shown in Fig. 4. The bunch shape development is drawn in Fig. 5.

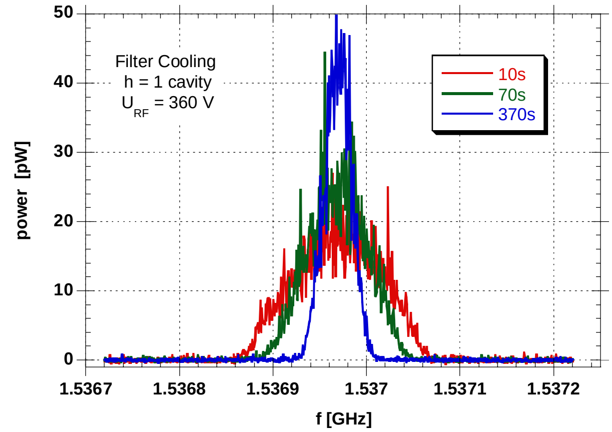

Figure 4: Power spectra at harmonic number 1000 for 10 s, 70 s and 370 s of cooling with cavity voltage 360 V.

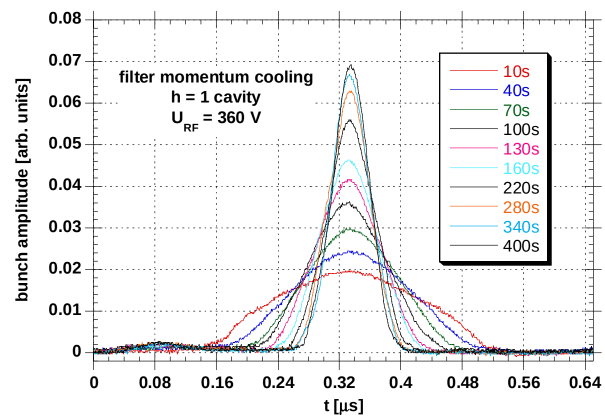

Figure 5: Bunch shape during Filter cooling for bunching with the h = 1 cavity at U_0 = 360 V.

From the figures one clearly concludes that both momentum spread and bunch length are reduced during momentum cooling. The rms relative momentum spread σ_δ and the rms bunch length σ_τ derived from the power spectra and the bunch shape measurement, scale with voltage U as $\sigma_\tau \propto U^{-1/4}$ and $\sigma_\delta \propto U^{1/4}$ [7]. The rms bunch area $B_{rms} = \pi\sigma_\tau \cdot \sigma_\delta$ is thus independent from U. It decreases during cooling by a factor of 15 as shown in Fig. 6. For the cavity voltage U_0 = 360 V the bunch length σ_τ is reduced from 0.1 µs to 0.02 µs within 390 s. The relative momentum spread σ_δ was cooled from $4.4 \cdot 10^{-4}$ to $1.4 \cdot 10^{-4}$ corresponding to a reduction of a factor of five and three, respectively. Fig. 6 additionally shows a simulation result for bunched beam cooling with a cooling system gain 110 dB and a cavity voltage 360 V. The data are remarkable well reproduced by the theoretical predictions. More details on bunched beam cooling simulations are accomplished in [6].

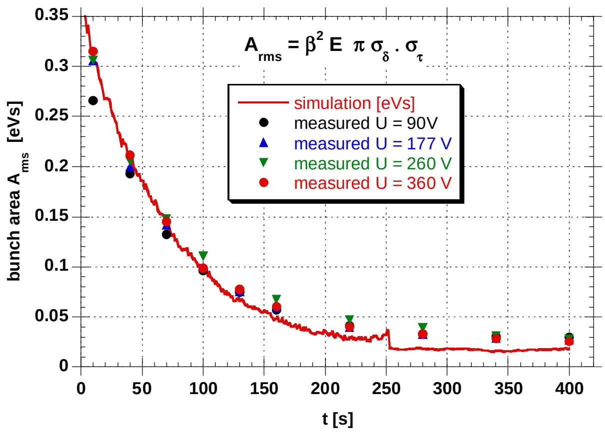

Figure 6: Bunch area during cooling for different cavity voltages 90 V, 177 V, 260 V and 360 V The curve represents the simulation result for the h = 1 cavity voltage 360 V and cooling gain 110 dB.

Mean Energy Loss Compensation with Barrier Bucket Cavity during Filter Cooling

It could be demonstrated at COSY with a 2.6 GeV/c proton beam that the mean energy loss induced by an internal pellet target similar to that coming into operation at the HESR could be compensated and cooled in momentum with the stochastic cooling system, Fig. 7.

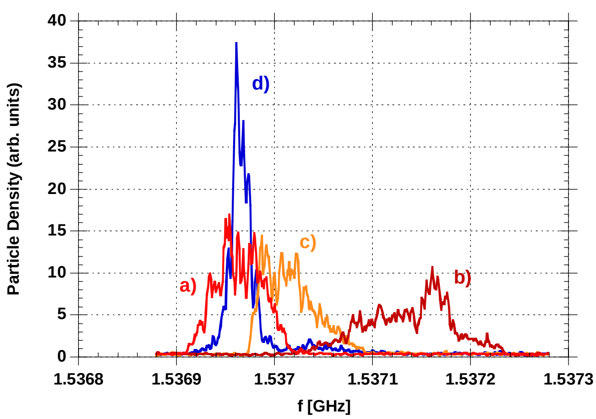

Figure 7: Schottky spectra of a COSY proton beam measured at the 1000th harmonic: a) initial distribution; b) distribution after 180 sec only pellet target, the energy loss led to a shift to higher frequencies since $\eta < 0$; c) only pellet-target and cooling; d) after 180 sec with cooling and barrier bucket as well as target.

The mean energy loss was determined from the shift of the center frequency due to the beam-target interaction only. A target thickness of $N_T \approx 3 \cdot 10^{15}\ atoms / cm^2$ was deduced.

The synchrotron motion of particles in the barrier bucket has been investigated with a numerical tracking code including the beam-target interaction and stochastic momentum cooling with band II [6]. The simulation is displayed in Fig. 8 which remarkably well predicts the measured particle density in Fig. 7.

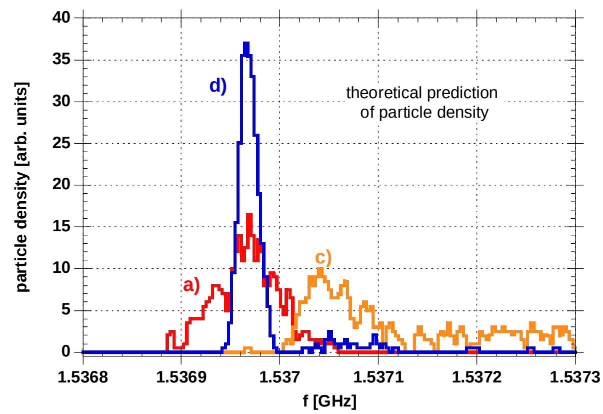

Figure 8: Simulated Schottky spectra of a COSY proton beam measured at the 1000th harmonic: a) initial distribution; c) after 180 sec, only pellet-target and cooling; d) after 180 s with cooling, BB cavity and target.

SUMMARY AND OUTLOOK

Power spectra and bunch shape measurements have been carried out for bunching with harmonic number one and different voltages. The bunch area reduction during cooling was found in a good agreement with a theoretical prediction. It was observed that particles initially being outside the stable bucket area can be efficiently cooled into the bucket. Cooling with a barrier cavity is similar but faster since the beam is almost DC. The barrier bucket cavity was applied to compensate the mean energy loss induced by a pellet target. Momentum cooling reduced the beam momentum spread. The behaviour is well described by theoretical predictions. Further experiments will be carried to improve the models and BB operation.

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