LATTICE OPTIMIZATION FOR THE STOCHASTIC COOLING IN THE ACCUMULATOR RING AT FERMILAB

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Abstract

New efforts are under way at Fermilab to increase the rate of antiproton production. This program includes optimization of machine optics in the Antiproton Accumulator to improve stochastic cooling. The new lattice was implemented in May of this year. Results are discussed, as well as some aspects of model development and lattice measurements.

INTRODUCTION

A broad effort to increase antiproton production for the Tevatron accelerator complex at Fermilab was initiated in 2005. The goal was to optimize the performance of all machines in the production chain: Booster, Main Injector, Debuncher, Accumulator and beam lines, in order to maximize the flux of antiprotons to the Accumulator. This effort succeeded in reaching the peak rate of 20 mA/hr in February 2006.

Further increase of the stacking rate was limited by the capability of the stacktail stochastic cooling system in the Accumulator such that any further increase in the incoming flux would not result in an appreciable increase in the antiproton accumulation rate.

The new effort that started after the shutdown of 2006 concentrated primarily on the stacktail cooling system. Subsequently, there was a further increase in the peak rate (23mA/hr in April, 2007), but more importantly, also the average stacking rate. This progress, combined with very successful improvements in the Fast Transfer Protocol [1], resulted in nearly doubled average weekly production of antiprotons for the Tevatron in March, 2007.

A significant outcome of this effort was the development of an integrated physics model of Accumulator stochastic cooling [2] that identified physical and technological limitations of the system, as well as the way to improve its performance. Here we discuss the optimization of the Accumulator lattice as suggested by this model, the implementation of the optimized lattice, and first results.

ACCUMULATOR LATTICE

The Accumulator has a periodicity of 3, and mirror symmetry in each of 3 sectors. It has 3 straight sections and 3 arcs. The Accumulator lattice functions are shown in Figure 1. Continuous injection of the antiproton beam from the Debuncher is maintained using stochastic stacking. Beam arrives at the injection orbit at an energy that is approximately 140 MeV higher than that of the circulating core beam. 100 msec later the injected beam is adiabatically bunched and RF displaced to the deposition orbit, which is approximately at the center of aperture. From this point it falls under the action of the stochastic cooling force (Stacktail system) that starts pushing it towards the main core beam (60 MeV below the central orbit energy). A 6D-cooling of the main core beam is performed by separate core stochastic cooling systems.

Large dispersion in the arcs (10m) separates the beam according to energy, whereas in straight sections beams of all energies are merged together and compressed in order to fit into the very narrow aperture of the stochastic cooling tanks. Beam focusing and flattop dispersion in the arcs are maintained by the quad quadruplets on each side of the small straight sections inside the arcs. These high dispersion sections house extraction/injection kickers and the momentum stochastic cooling pickups. In the long straight sections the dispersion is cancelled at the small bend magnets on each side. These low dispersion sections accommodate stochastic cooling kickers, RF cavities, a DCCT transformer, and dampers.

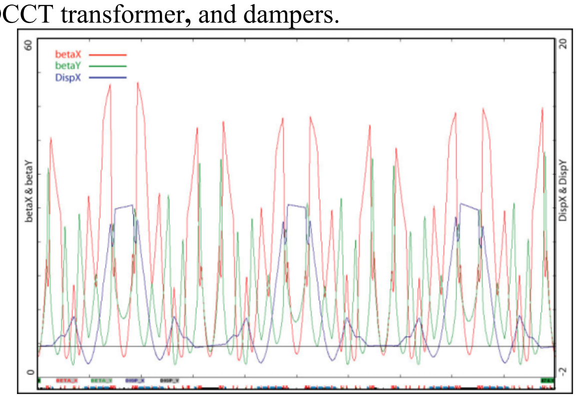

Figure 1: Accumulator Twiss-functions. Red and green traces show the horizontal and vertical beta-functions. The horizontal dispersion is shown with the blue trace.

It is important to keep dispersion as low as possible in the long straight sections. Any residual dispersion here would couple the longitudinal kicks of the stacktail kickers into the transverse dimensions causing transverse heating of the beam.

LATTICE OPTIMIZATION

Objectives

The main objective for the lattice optimization was to increase the slip factor (η). This would directly help the stack tail cooling as the maximum flux is proportional to η [2]:

$$J_{\max} = |\eta| T_0 W^2 x_d$$

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The maximum useful value of η is limited by overlapping schottky bands at high harmonics ("bad mixing"), but there is still some room (15-20%) available, according to the model of the stacktail cooling [2].

Another benefit of raising the slip factor is additional separation of the stacktail and core revolution frequencies**.** This would mitigate the effects of resonant heating of the core. It has been found recently that the electrical center of the core momentum kickers depends on frequency and shifts to about 2mm at 3.3GHz [2]. This heats particles in the core whose transverse sidebands overlap with the stacktail harmonics at 3.3 GHz. Figure 2 shows the calculated emittance growth rate for a particle with a given revolution frequency. The vertical dash marker shows the center position of the core particles. Separation of the core and stacktail would better center the core between the two sideband peaks, thus reducing the heating of the core particles.

Great attention has been paid to the dispersion reduction in the long straight sections. As the standard mults affect the slip factor, they are only used for the fine

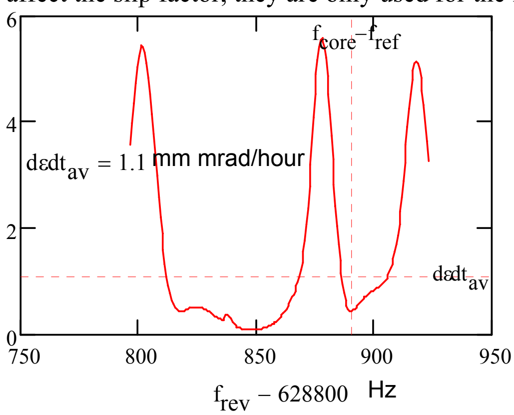

Figure 2: Emittance growth rate versus the particle frequency due to resonant heating at 3.3GHz. Vertical dash line shows the location of the core. Horizontal dash line shows average core heating rate due to this effect.

tuning, and the main corrections were made within the lattice change.

It was very desirable also to increase the design machine aperture to at least 14-15π mm-mrad. Presently the machine admittance is limited at 8-10π mm-mrad and is not very well understood. Compressing the beam size at most narrow locations may improve the admittance.

Lattice Model

For optics calculations in the Accumulator ring we utilized a model based on the OptiM program [3]. The model parameters were fit to the measured data taken in May, 2007. The method is similar to that we used earlier for the Debuncher ring [4].

Model calibration data was taken as difference between positive and negative closed orbit bumps produced by each corrector magnet in the machine. In this case small orbit drifts during the measurement cancel out. As the orbit measurement precision is crucial for the calculations, each orbit was sampled 15-20 times. The combined response at each Beam Position Monitor (BPM) to the excitation of each corrector determines the Response Matrix (RM). For the dispersion measurement a revolution frequency scan of 5 steps around the equilibrium orbit was taken making the maximum variation of momentum equal to 0.1%. Figure 3 shows these measurements for the BPMs located at low dispersion regions. The estimated sensitivity of this method is about 1mm in dispersion units. The whole process of measurement is automated and takes about 1-1.5 hours.

The data have been analyzed using the *SRLOCOFitting* program. This package has been developed at ANL [5] and recently adopted at FNAL [6,4]. It fits the model parameters to minimize the differences between the calculated and the measured RMs.

The main difficulties of lattice fitting are the limited precision of the BPMs and a very limited number of the correction elements in the Accumulator. In this case the Singular Value Decomposition (SVD) algorithm used by *SRLOCOFitting* turned out to be very efficient.

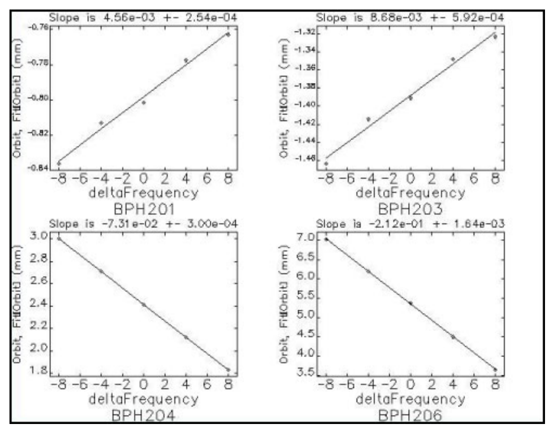

Figure 3: Dispersion measurement as a slope of orbit displacement with momentum varied within ±0.1%.

The average residual rms on the response matrix fit is 10-15 micron. From this we estimate the accuracy of the beta-function calculations to be about 5% or better. The method was used not only to find out the quad errors, but also to determine separately instrumentation errors (like BPM calibration and trim magnet strength corrections). Also, many other variables can be included in the fit, as long as they can serve as model parameters.

Optimization

In order simulate the desired solution for the new lattice we have started with the existing model with the new fitted parameters in the beam line mode. In this case one can model sequential changes that shape only the downstream lattice functions. At the end of the process, when reaching the end of the line, final functions have to be matched to functions at the beam line beginning to satisfy the closure condition. This procedure is repeated iteratively until an acceptable solution is reached. Flattop dispersion in the arcs is constrained to be kept at the same level. In order to increase the slip factor we varied the dispersion function in the negative wells, see Figure 4.

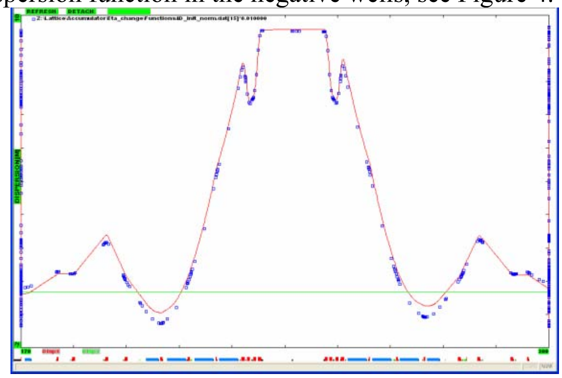

Figure 4: Dispersion corrections made to increase the slip factor. Red trace shows the new dispersion and blue data points correspond to the old lattice. Dispersion is changed in the negative wells and preserved at the flattop.

The slip factor has been increased by 15% in the final lattice design (0.012 → 0.015). Also we reduced the beam size at 6 most narrow locations (4 of them in horizontal plane and 2 – in vertical plane). This brought the minimum design aperture from 11 π up to 15 π. The new design also has smaller average beta-functions which reduces the IBS heating term by 12%. Stochastic cooling pickup to kicker phase advances were corrected also, although those were already fairly close to required values.

Results

Direct implementation of the new lattice design was complicated due to an additional operational step that we had to do in parallel. We had to change the bus cycling protocol, because it contained the historically obsolete procedure of double lattice ramping. So, the hysteresis protocol was not the same as for the old lattice. However it turned out that the difference was limited to just tune corrections, so we proceeded smoothly after this was taken into account.

The new slip factor was measured to be very close to the design one. This was proved by using two independent methods of slip factor measurement. One method was the direct measurement of gamma-t factor from the measurement of revolution frequency response to bend bus variations**;** and another method extracted the slip factor from the synchrotron frequency dependence on the RF voltage.

Because the requirement on dispersion suppression in the straight sections is so tight (<5cm, compared to the flattop dispersion of 10m!), it took 2 iterations of dispersion corrections. In the final measurement this dispersion was made lower than 2.5 cm. Final measurements have also shown that the minimum design aperture in the Accumulator ring has increased to 15 π.

The new lattice was implemented in the Accumulator and made operational as of May 16 this year. The observations of its immediate effect on stacking are not very conclusive because it was made concurrently with other changes in the stack tail system as well as temporary degradation of the incoming flux to the Debuncher. A better evaluation will be available later this year at the completion of the whole project. However a very important immediate effect of new lattice was in the substantial reduction of the transverse heating. Figure 5 shows average core emittances within a period of one month before and one month after the optics change.

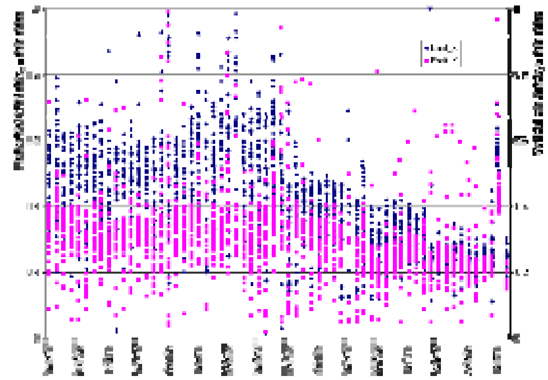

Figure 5: Accumulator transverse emittances. The break point corresponds to the day of the new lattice implementation.

High transverse emittances affect the efficiency of antiprotons transport to Recycler and, therefore, the Tevatron operations. Stacktail performance is also constrained by the core heating, so reduction of emittances gave more freedom for the stacktail optimization.

Conclusions

The new model of the Accumulator lattice has been developed using the OptiM and *SRLOCOFitting* software. Based on this model lattice optimization has been performed in order to help stochastic cooling. The new lattice design was implemented and subsequent measurements have shown that design parameters were achieved. Substantial reduction in the core transverse heating has been observed.

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