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Intrabeam Scattering in the Fermilab Antiproton Accumulator*

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Abstract

The growth rate of the horizontal and vertical emittance in the accumulator ring at Fermilab has been measured with 97.8×10^{10} antiprotons starting with completely cooled beam. We find that the emittance growth rate can not be fully explained by the existing intrabeam scattering calculations done including the detailed lattice of the storage ring.

I. INTRODUCTION

Recently a number of upgrade projects have been undertaken at Fermilab accelerator facility to improve operating conditions and be able to provide better quality beams. In this program, improving the performance of the antiproton storage ring, the accumulator, plays an important role both in the collider mode of operation of the Tevatron as well as the fixed target mode with antiprotons. This storage ring was originally built[1] for a final stack of 50mA (1mA $\simeq .9928\times10^{10}$ particles at about 8 Gev/c for the Fermilab accumulator ring) $\bar{p}$ with a momentum spread of $\pm0.025\%$ and horizontal and vertical emittance of $2\pi - mm - mr$. But we have achieved $\bar{p}$ stacking in the accumulator ring up to 120mA, about a factor of two larger than the design intensity. We have also stored protons up to about 125mA during one of our runs dedicated to improve the storage ring performance. With the proposed Main injector we expect the maximum stored beam as high as 250-300mA. But, the limitation in the maximum stacking of antiprotons achievable in the accumulator could arise from intrabeam scattering. Hence it is highly interesting to investigate emittance growth of the stored beam in the accumulator.

The emittance growth in a storage ring for coasting as well as for the bunched beam due to intrabeam scattering is a rather well known subject. The initial theory of intrabeam scattering without including the detailed lattice of the ring was developed by Piwinski[2]. Further development lead to the inclusion of a general lattice[3,4]. A direct testing of the theory of intrabeam scattering was done at the CERN antiproton accumulator ring and a reasonable agreement was obtained except for the vertical emittance growth rate[5].

In this paper we present results of our measurements on transverse emittance growth in the accumulator ring and comparison with the existing intrabeam scattering theory[3].

II. MEASUREMENTS AND DATA ANALYSES

During one of our $\bar{p}$ source study period we stacked about 100mA of $\bar{p}$ beam in the accumulator ring. Throughout stacking the core of the beam was cooled using high frequency momentum and transverse stochastic cooling systems[1]. After the stacking was stopped the cooling was left on for about 2-3 hours until a steady state beam temperature was reached (i.e. a balance between cooling and self heating was achieved). The initial beam parameters were,

$$\text{Number of } \bar{p} = 98.5\text{mA} \ (\gamma=9.48 \text{ at kinetic energy of } 7.95\text{GeV})$$

$$\epsilon_H = 1.50\ \pi\text{-mm-mr}$$

$$\epsilon_V = 1.22\ \pi\text{-mm-mr}$$

$$\left(\frac{\Delta p}{p}\right)_{99\%} = \pm9.99\times10^{-4}$$

$$\text{Vacuum} \simeq 4.0\times10^{-10}\ \text{(Torr)}$$

(life time about 800hr).

Where, ϵ_H and ϵ_V are horizontal and vertical emittances of the beam and Δp is momentum spread. Then, only the transverse cooling was turned off and the $\bar{p}$ stack was left to blow-up in the transverse plane. The emittance growth was monitored for about 3 hours. To monitor the emittance growth we used two different methods. In both cases the betatron side-band powers were measured which are directly proportional to the emittances of the beam, i.e. $\epsilon_{H,V}=\alpha P_{H,V}$. In the first method, the emittance measurements was done continuously by using a pair of schottky pick-up systems which were pre-tuned to the horizontal and vertical side-bands[6] and thereby measuring the powers. In the second method, spectrum analyzer measurements were taken of the schottky power once every five minutes and the power in each side-band is extracted from the spectra. In both cases the calibration constants α come from separate measurements with scrapers. For this we used slowly heated beam which gives a gaussian beam profile. The beam size measured using scraper is related to the beam emittance by[7],

$$\epsilon_{H,V} = \pi \frac{6\sigma^2_{H,V}}{\beta_{H,V}} .$$

Where σ the is size of the beam in the horizontal or vertical plane and β is the betatron function. The measured emittance by these methods have less than 5% errors. The Figures 1 and 2 show the time evolution of emittances ϵ_H and ϵ_V (95% of the particles

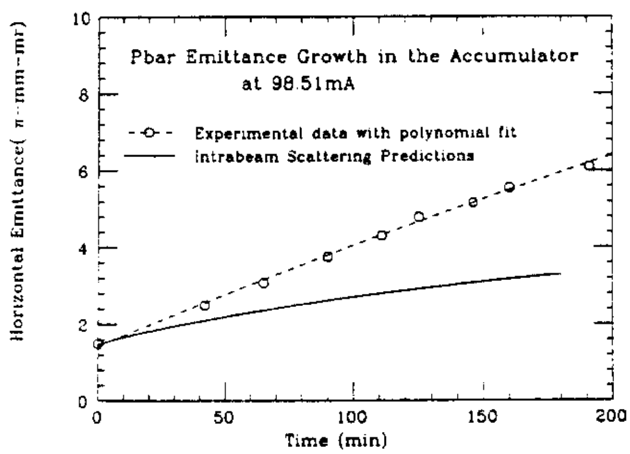

Figure 1. The Horizontal emittance versus time.

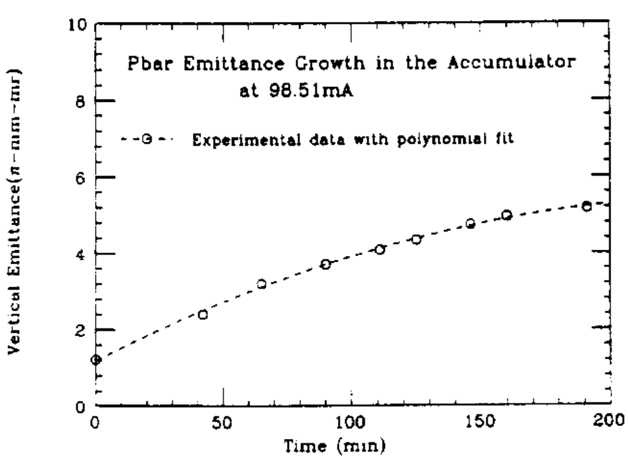

Figure 2. The vertical emittance versus time.

in phase space) respectively. The time t=0 corresponds to when the cooling was switched off. With in about three hours the emittances grew by a factor of four. The accumulator ring has horizontal and vertical acceptances of about $10\pi - mm - mr$ which are larger than the maximum emittances we reached.

To understand the emittance growth we carried out a number of intrabeam scattering calculations using a computer code obtained from CERN[3]. This uses the beam properties, betatron function of the accumulator ring as well as the dispersion functions and derivatives of the betatron functions as inputs. The results of calculations for horizontal emittance growth is shown in the figure 1 by a solid curve. The measured horizontal growth rate is larger than the intrabeam scattering predictions. This indicates that, there is some unknown heating mechanism that is larger than intrabeam scattering. We have calculated the contributions to the emittance growth arising from multiple Coulomb scattering on the residual gas and find the rate to be approximately $0.1\pi - mm - mr$/hr. As a check the calculated lifetime from nuclear and single Coulomb scattering is 1000hours compared to the observed lifetime of 800hours.

In the case of vertical emittance, the growth rate from intrabeam scattering is predicted to be negative. However, it is important to note that the model used does assume no coupling between horizontal and vertical betatron motions. But in reality the coupling in the accumulator is significant and we do not really expect to see damping of the vertical motion. In addition, the vertical motion may be subject to other heating mechanisms.

III. SUMMARY

We have measured the emittance growth in the Fermilab $\bar{p}$ Accumulator ring with a stack of about 98.5mA of antiprotons. The data have been compared with the intrabeam scattering model predictions. We find the observed growth rate is not explained by the intrabeam scattering model or by multiple Coulomb scattering.

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