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Emittance at the Brookhaven AGS*

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The emittance measurements at the AGS have been of limited importance to the actual machine operation and of questionable accuracy. However with the unprecedented intensity achieved in the AGS, emittance questions are coming to the fore.

The recent intensity history of the AGS is shown in Figure 1. Significant increases in intensity were achieved through significant machine improvements. In 1984 with H^- injection, in 1993 with the new 2.25 GeV Booster, and in 1994 with a new rf system in the AGS that enabled it to utilize the intensity from the Booster. The present intensity of 4 x 10^{13} protons per pulse is a record for proton synchrotrons but still short of the design goal of 6 x 10^{13} ppp that should be achieved in 1995. The design of the Booster was based on our experience with the AGS, which seemed to operate well with a tune shift as large as 0.7. Figure 2 shows the expected tune shift in the Booster and the stopbands that had to be corrected to achieve full Booster performance. The tune shift calculation uses a simplified Laslett formula but the crucial parameters are the assumed beam dimensions and shapes, both transverse and longitudinal.

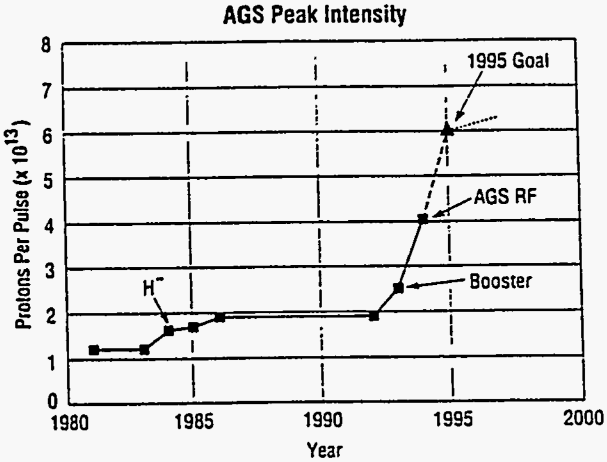

Figure 1.

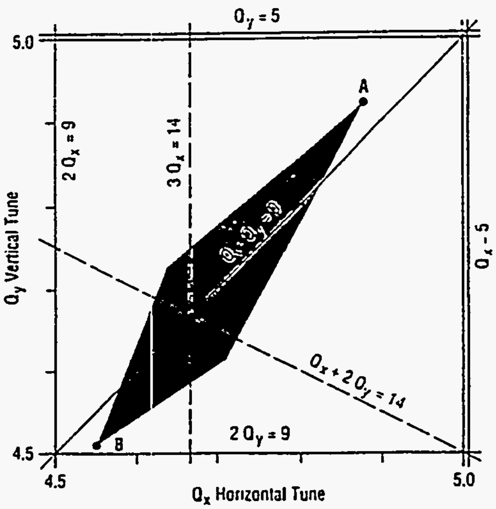

Figure 2.

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The transverse beam dimensions in the AGS have been measured for many years with an Ionization Profile Monitor (IPM). In the Booster an IPM with a microchannel plate is used because the high Booster vacuum yields few ions. The IPM is a useful device except it has one well known systematic problem. The electric field of the proton beam affects the flight path of the ions with the result that at high intensity and, in particular, at high energies, when the actual beam size is small, the measured beam size is too large. This effect can be calculated, but only to a limited degree of confidence, leaving unanswered the question as to whether the emittance in the AGS grows with energy. In the Booster it is possible to run the beam up to full energy and then to decelerate it back to low energy on the down ramp of the magnet. The measured normalized emittance grows and then shrinks with decreasing energy, leading to the conclusion that the apparent growth must be an artifact of the IPM. Such data will enable us to determine reliable emittance values for the Booster, but for the AGS we must add a wire scanner to establish an absolute calibration. Absolute knowledge of the emittance is desirable in the present circumstances since in order to maximize intensity it is useful to maximize beam size, however the limiting apertures are the injection and extraction devices in the Booster and the AGS, which means there are now tight constraints on the beam size as well as on the quality of the matching that must be done between the machines.

Another problem in determining emittance from an IPM is in the fact that the horizontal beam size is determined from both the horizontal emittance and the momentum spread. The recently commissioned system for jumping the beam rapidly through transition, serendipitously provides us with a very nice procedure for disentangling these two components. Figure 3 shows the horizontal beam size measured by the AGS IPM over a short time span near transition. The measured size is given by:

$$x = \sqrt{E\beta + (D\Delta p/p)^2}$$

where:

E = Horizontal emittance
β = Beta function at IPM
D = Dispersion function at IPM
$\Delta p/p$ = Momentum spread in beam

To move the beam rapidly through transition, a set of fast quadrupoles are turned on and ramped up to a high field in 60 milliseconds. This keeps the transition energy of the machine above the beam energy. The quads are then turned off in a millisecond, driving the beam quickly through transition. One effect of the quads is to change the dispersion function of the machine. In the AGS it starts out positive, moves through zero to a large negative number and then at transition swings rapidly back through zero to its original value. When the dispersion function goes through zero, the measured beam size goes through a minimum that is just the emittance of the beam. Using this value for E, the formula enables us to calculate D $\Delta p/p$, which is plotted in Figure 3. This data confirms the modelling calculations of D and measures $\Delta p/p$.

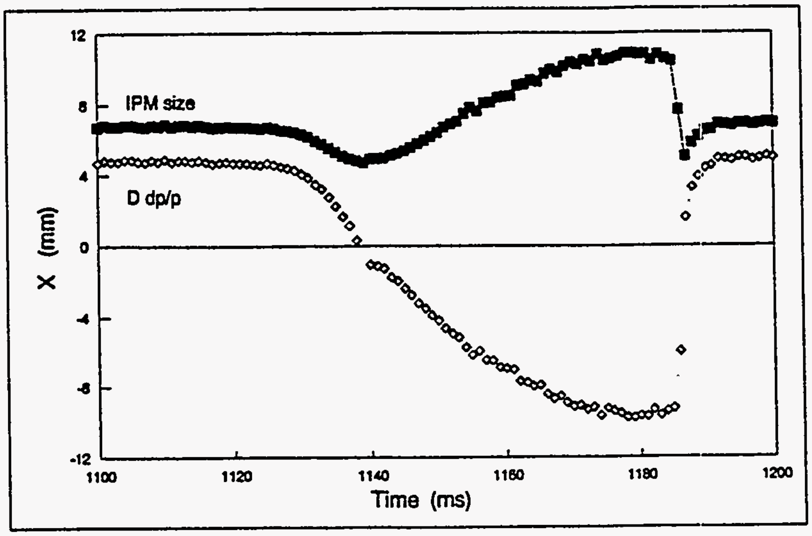

Figure 3.

Figure 4 shows another interesting effect. When the horizontal and vertical tunes are crossed and then recrossed, the betatron amplitudes are exchanged resulting in the very dramatic change in beam sizes shown in the figure.

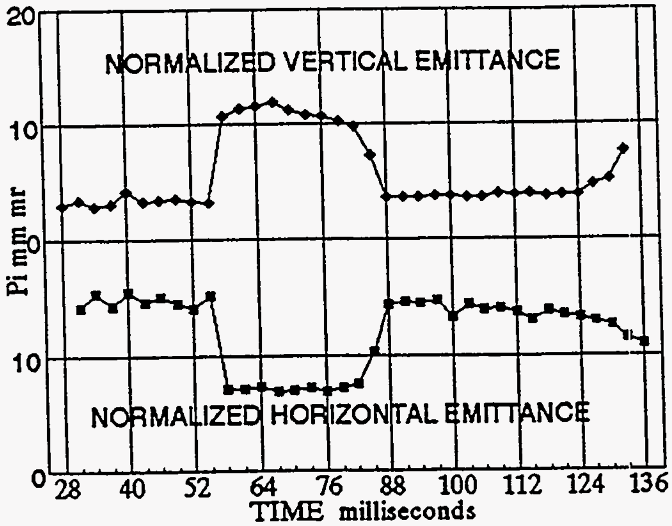

Figure 4.

For 1995, the program at the AGS will include maximizing the intensity by painting the injected beam to increase the emittance while minimizing losses by matching the beam emittance to the admittance of the extraction and injection devices.