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A STRETCHER FOR THE BROOKHAVEN AGS* -2

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ABSTRACT This paper summarizes the conceptual design of a 30 GeV Stretcher ring,[1] which is designed to increase the capacity and the quality of the experimental physics program at the AGS. In a typical 3 second operating cycle the AGS now accomplishes two functions: accelerating the beam to full energy and then providing a slow spill on a 30 GeV flattop. These tasks consume approximately equal time. The proposed Stretcher, a dc storage ring, will take up the task of distributing the high energy beam with a continuous slow spill, making it possible for the AGS to provide beam for the program at more than twice the present repetition rate. Thus the average current delivered to the experimenters will be more than doubled, and the duty cycle of the spill will increase from the present optimum of about 40% to nearly 100%. The Stretcher will continue the gradual evolution of the AGS toward a kaon factory.[2] At present, the AGS provides about 1 μA average proton current. A Booster, now under construction,[3] is expected to increase the current to above 4 μa, and the Stretcher to about 8-10 μA, an order of magnitude higher than now.

INTRODUCTION

The 30 GeV AGS supports a great variety of experiments in high energy and nuclear physics. Its ongoing research program has provided the stimulus for numerous proposals for future high intensity hadron facilities: the study of very rare processes in kaon decays, the search for gluonic states, the study of QCD with high p_t exclusive processes, and many more. Several rare kaon decay experiments on the AGS floor at present, for example, can already be sensitive to effects from mass scales higher than what will be directly accessible with the SSC, and even higher sensitivity is sought for future experiments. Moreover, the AGS accelerates polarized protons, and provides heavy ion beams for fixed target experiments. There is now a clear call for higher intensity proton beams at these intermediate energies, and as the intensity increases, for improvements in the quality and duty cycle of the beam spill.

At the AGS these improvements are being provided in a step by step manner, in response to the most urgent needs of the physics program, in a way which minimizes the disruption of the ongoing operations. A Booster is now under construction[3] which will raise the injection energy of the AGS from 200 MeV to 1.5 GeV for protons, to increase the space charge limited intensity of proton beams by more than a factor of four, from an average proton current of about 1 μA at present to about 4 μA in the future. The Booster will also provide higher injection

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DISCLAIMER

energies for the heavy ions, so that even the heaviest species can be supplied to the AGS in the fully stripped state. This capability is important for RHIC, the proposed new Relativistic Heavy Ion Collider at BNL.[4] Finally, the Booster will serve as an accumulator of polarized proton pulses from the rapidly pulsing 200 MeV Linac, thus increasing polarized beam intensities by an order of magnitude as well.

When the Booster is completed, a 30 GeV Stretcher can be added to the AGS. It will take over from the AGS the task of providing a slow beam spill to the experiments. This will make it possible for the synchrotron to deliver beam at more than twice its present cycling rate, thus more than doubling the average current to 8-10 μA, while the duty cycle of the slow beam spill will increase from about 40% to nearly 100% (see Fig. 1). It is equally important to the experimenter that the microscopic structure of the slow spill be improved as well. Quite frequently, the AGS spill now shows instantaneous intensity fluctuations of a factor of 2 or more, so that the most sensitive experiments must throttle back their event rate to avoid excessive accidental coincidences with background events. With an improved spill structure expected from the Stretcher, such sensitive experiments may expect to perform at more than 4 times higher rates than would be possible with the Booster alone.

AGS STRETCHER DESIGN

The proposed AGS Stretcher[1] is equal in circumference to the AGS (~ 807.12 m). The ring is constructed in a separate tunnel, to the south of the AGS, in a two-fold symmetric racetrack pattern (see Fig. 2). It has two 86 m long straight sections which facilitate an optimal arrangement for the injection and extraction systems. Its easterly straight section serves for the extraction of the beam toward the existing East Experimental Area beam switchyard, the westerly one for injection. Beam is supplied by single turn beam transfer from the AGS. There is no rf system in this machine. The polarization of the beam is preserved during beam transfer, storage, and extraction. Construction and commissioning of the Stretcher can proceed with minimal disruption of the ongoing program.

The Stretcher is a "distribution ring", operating continuously at a constant energy, up to 30 GeV. It will be supplied with full energy beam provided by the AGS, which will be cycling at its maximum repetition frequency of about 0.6-0.8 Hz, and it will distribute this beam in a slow continuous spill, interrupted only briefly when the AGS is ready to supply a new pulse (Fig. 1). The AGS beam will arrive as a train of 12 bunches, separated by 224 nsec in time, having been extracted in a single turn over a time interval of 2.7 μsec. With an inherent momentum spread of ± 0.3% or more imposed by the AGS the beam will lose its bunch structure in about 20 msec. The Stretcher will then immediately start slow extraction toward the experimental areas, while the AGS is cycling back for the next pulse. Any beam which may remain in the ring when the next pulse is about to arrive, will be ejected to the beam dump by the same fast kicker magnet which deposits the arriving beam on the injection orbit. Overall, the injection operation will consume less than 5% of the entire spill time, so that the slow spill duty cycle will be greater than 95%.

The Stretcher will be available for all AGS programs which use the slowly extracted beam in the East Experimental Area: unpolarized high intensity proton beams, polarized proton beams, and heavy ion beams. The fast, single turn extraction of bunched beams, traditionally employed for neutrino physics and for other specialized experiments, will remain available directly from the AGS in the North Experimental Area, as before.

LATTICE AND STRAIGHT SECTION DESIGN

Figure 3 shows one quarter of the ring in further detail. The 86 m long straight sections are dispersion-free, and there are 34 separated function FODO cells in the arcs, including the dispersion suppressors, with a 60 degree betatron phase advance per cell. The straight sections represent approximately one betatron wavelength each. The machine operates near a tune of about 7.7 in both planes, in fact on the horizontal 7 2/3 resonance for slow extraction most of the time.

The betatron functions of the lattice are illustrated in Figs. 4.a,b,c for the arc cells, the dispersion suppressor, and for the straight sections, respectively. The six quadrupoles at each end of the arcs are individually powered so as to achieve the desired match into the straight sections with zero momentum dispersion.

Each straight section contains ten quadrupoles arranged symmetrically around its center, and the betatron functions in the central portion can be adjusted to optimize the performance of the extraction and injection systems. The electrostatic extraction septum is located in the central 10 m long free space of the easterly straight section, the injection kicker in the westerly one in the same space (Fig. 5).

The natural chromaticity of the lattice is about -14. One makes use of the chromaticity to drive particles of different momentum across the resonance at different times. Sextupoles are included in the dispersion supressor sections. They can be set to make the dispersion cancellation in the straight sections independent of momentum, without affecting the chromaticity in a major way. A summary of the major Stretcher parameters is given in Table 1.

TABLE 1. STRETCHER PARAMETERS

Momentum	30 GeV/c
Magnetic Rigidity	100 Tm
Circumference	807.12 m
Periodicity	2
Straight Section Length	86 m
Cycle Period	1.2 sec
Protons/Cycle	$>6 \times 10^{13}$
Normalized Beam Emittance	60 π mm mrad
Betatron Admittance	10 π mm mrad
Momentum Acceptance	± 1%
Betatron Tune	7.667
Natural Chromaticity	-14
Transition Energy, Gamma	6.5
Dipole Field	1.26 T

SLOW BEAM EXTRACTION

The beam is extracted from the machine by exciting a third order resonance, $3\nu_x = 23$, and by slowly changing the horizontal tune to drive particles of different momentum across the resonance as time evolves. Unstable particles will spiral outward into the electrostatic septum, which deflects them horizontally into a Lambertson septum magnet, which in turn deflects them vertically out of the ring. The layout of the extraction straight section is illustrated in Fig. 5.

The third-order resonance is established by powering a pair of small sextupoles, located next to the two quadrupoles denoted as Q5 and Q3 upstream of the electrostatic septum. The betatron tune of the machine is driven by four small auxiliary quadrupoles located symmetrically next to each of the quadrupoles denoted as Q1, in both straight sections.

The optical parameters of the straight section are flexible to permit a choice of beta values at the extraction septum. The horizontal beta value at the extraction septum is chosen to be 250 m, subject to further optimization in the future. The spiralling rate is 2 cm, and the electric field is 60 kV/cm across the 2 cm gap of the electrostatic septum. The septum is assumed to be 9 m long, curved at half the curvature of the extracted beam. Assuming a wire thickness of effectively 0.05 mm, one expects a loss of about 0.3% of the beam on the septum.

A simulation of the extraction process in horizontal phase space at the electrostatic septum is illustrated in Fig. 6. The septum is placed about 6 cm to the outside of the central orbit. The illustration shows unstable particles of several momenta leaving the stable region near the center along the separatrices of the third order resonance, with a spiralling rate, near the septum, of about 2 cm for every third turn.

It is expected that a small fraction of the beam will remain in the ring without having responded to the resonance. While a fresh pulse arrives from the AGS, whatever beam may have remained in the Stretcher will be ejected by the injection kicker magnet onto a beam dump, on a trajectory which mirrors the injection path (Fig. 5).

POLARIZATION

The Stretcher will preserve the vertical polarization of the beam, as the AGS does now, if the energy is chosen to avoid the various depolarization resonances.[5] Depolarization occurs at energies where the beam encounters certain lattice harmonics of horizontal magnetic fields in resonance with the frequency of precession. Depolarization can be caused by the intrinsic focusing fields of the quadrupoles - intrinsic resonances, where $G\gamma = nP \pm \nu_z$ - or by the horizontal imperfection fields due to, for example, improperly aligned quadrupoles - imperfection resonances, where $G\gamma = k$. Here $G = g/2 - 1 = 1.79285$ is the anomalous magnetic moment of the proton, γ is the energy of the proton in units of its rest energy and ν_z the vertical betatron tune. The indices n and k are integers, and P is a periodicity of the focusing lattice.

Imperfection resonance harmonics are therefore spaced about 0.523 GeV apart on the energy scale, and because of the 2-fold lattice periodicity intrinsic resonances are present within all of these intervals as well. An analysis of the strength of these various effects shows[1] that the most significant intrinsic resonances to be avoided are in the vicinity of 14.8 and 20.8 GeV ($G\gamma = 34 - (\nu_z - 2)$, and $= 34 + (\nu_z - 2)$, reflecting the very strong 34-fold periodicity of the arc cells, and the approximate transparency of the straight sections). The imperfection resonances in this vicinity tend to be strong as well.

Most resonances in the Stretcher are expected to be sufficiently weak so that one may operate in the energy intervals between them, as one does at the AGS, avoiding the neighborhood of the strongest intrinsic resonances, and if necessary suppressing the nearest imperfection harmonics with a compensating set of dipole correction magnets. The AGS has reached polarized beam energies up to about 22 GeV ($G\gamma = 43$), with polarization about 50%, using these techniques.[5]

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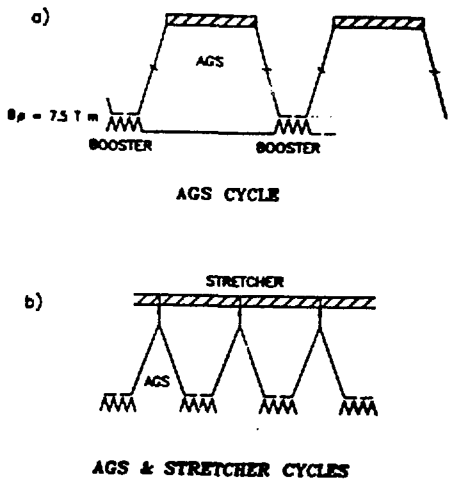

Fig. 1. AGS Cycle with and without Stretcher.

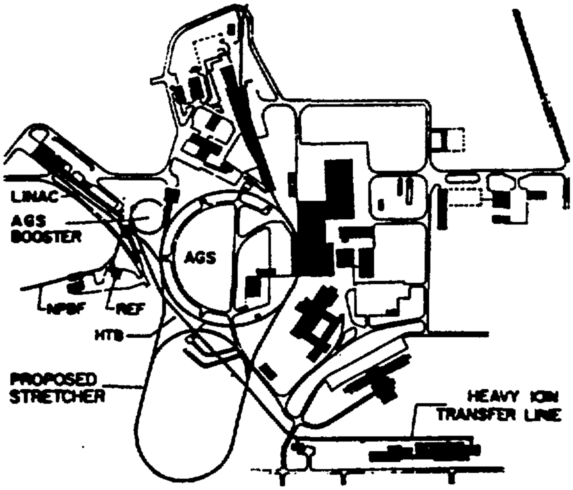

Fig. 2. AGS Stretcher Layout.

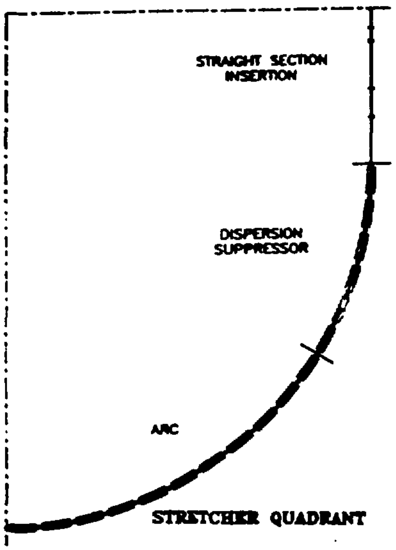

Fig. 3.

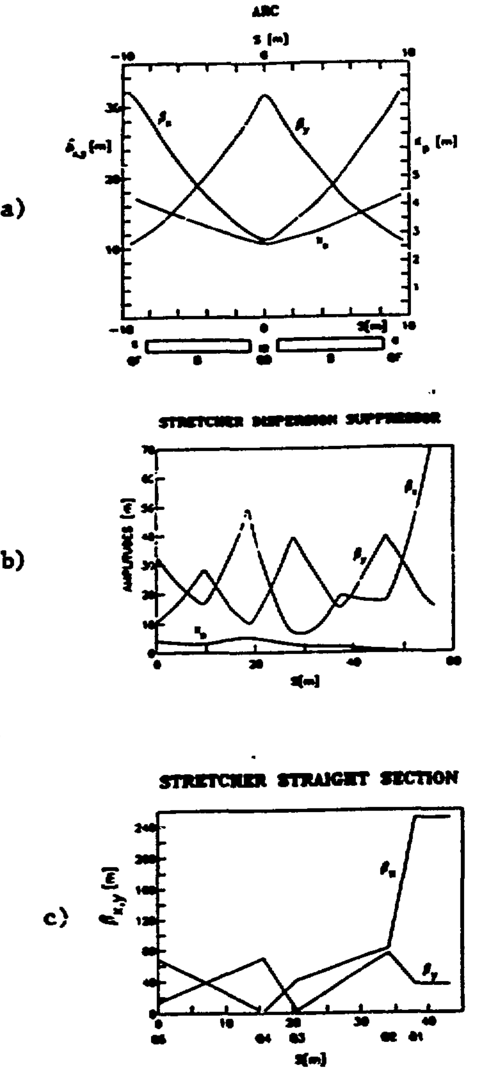

Fig. 4-a,b,c Betatron Functions.

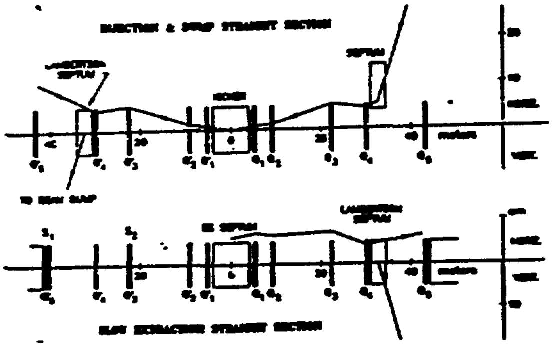

Fig. 5. Straight Sections

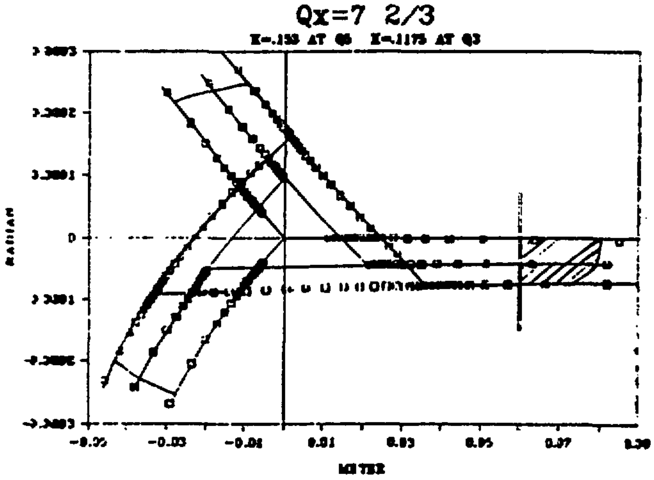

Fig. 6. Resonance Extraction Trajectories at Electrostatic Septum.