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PROGRESS AND STATUS OF THE AGS BOOSTER PROJECT*

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1. INTRODUCTION

New physics opportunities, such as: rare K-decay, neutrino and heavy ion physics demand that a rapid-cycling high vacuum and high intensity Booster be built for the AGS at Brookhaven National Laboratory.

The circumference of the Booster ring is one-quarter that of the AGS. Three modes of operation for various particles are envisioned. For unpolarized protons, four Booster pulses would be injected at a 7.5 Hz repetition rate within a 400 ms flat bottom of the AGS, enabling the present 1.5×10^{13} ppp to be increased to 6×10^{13} ppp. The protons would be accelerated to 1.5 GeV although the bending capability provided for heavy ions would eventually allow protons to be accelerated to 2.5 GeV. For heavy ions the rep rate is about 1 Hz and only one pulse would be injected into the AGS. For polarized protons 20 or so pulses can be stored in the Booster ring before injecting them into the AGS. Provisions for mixed modes of operation into a super cycle has been provided for future needs.

In Section 2, the lattice design and magnet characteristics will be briefly reviewed. In Section 3, major design issues will be discussed and design choices explained. Finally, in Section 4, the construction status and schedule will be presented.

2. LATTICE and MAGNET DESIGN[1]

The Booster ring consists of 24 FODO cell. Phase advance per cell is 72° which gives tune of 4.82 in each plane. Twelve straight sections are created by missing twelve dipoles from inter-quadrupole space re-

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sulting in 36 dipoles bending 10^{o} each. The final superperiodicity of the machine is 6. Major lattice and magnet parameters are listed in Table 1.

TABLE I Booster parameters

Circumference	201.78 m	β_{max}/β_{min}	13.5 m/3.5 m
ν_x/ν_y	4.82/4.83	$x_{p,max}/x_{p,min}$	3.1 m/0.7 m
No. of Dipole	36	No. of Quadrupole	48
Length of Dipole	2.4 m	Length of Quad	0.5 m
Gap Height/Width	75/152 mm	Bore Radius	76 mm
B_{max}	1.275 T	Gradient (max)	1.2 T/m
$\Delta B/B/_{rms}$	2×10^{-4}	$\Delta G/G_{\ rms}$	10^{-3}

The choice of optical functions and magnet aperture is predicated on the requirement of accepting high intensity proton without excessive space charge tune shift at injection.

3. MAJOR DESIGN ISSUES

Since the Booster is designed to meet three operational goals, the accelerator physics and component design requirements are more complicated then typical accelerator serving single purpose. In the following, some of those issues as well as the proposed solutions related to fast cycling high intensity proton acceleration will be discussed.

3.1 Space Charge Tune Shift. Based on the expression for space charge tune shift[2],

$$\Delta\nu_{sc} = \frac{3r_pN}{2B\epsilon_N\beta\gamma^2}$$

and the design value of bunching factor B = 1/3, normalized vertical emittance $\epsilon_N = 45 \times 10^{-6}$ mm -mrad, design intensity of 1.5×10^{13} ppp and injection energy of 200 MeV, the expected maximum vertical tune shift is about 0.35 units as shown in Fig. 1.

The expected shift at injection is larger than what conventionally thought to be reasonable design goal, but is substantially lower than what have been achieved both at the AGS and PSB at CERN which is 0.7 unit. Experiences showed that space charge tune shift is not a

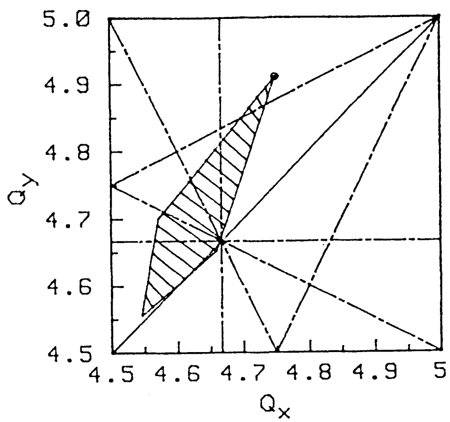

FIGURE 1 Space charge tune shift at injection

phenomenon with threshold behavior to constitute a hard limit. There are numerous ways to counteract the large tune shift at injection. Some of them are: a) stopband correction for 1/2 and 1/3 integer resonances to minimize the amplitude blow up due to resonance crossing, b) large RF voltage to reduce the bunching factor and to facilitate optimal capture and bunching operation, c) beam loading compensation to ensure proper voltage amplitude and phase function, d) sufficient physical aperture to keep beam with large momentum spread during capturing, e) shape the charge distribution to reduce peak intensity by phase space painting and 2nd harmonic cavity.

3.2 Eddy Current Effects. For proton operation, the Booster has to be ramped at 7.5Hz which amounts to a maximum $\dot{B}$ of 8T/sec. This induces eddy current on the vacuum chamber wall causing both field distortions and wall heating. The typical solution of using ceramic chamber is not acceptable in UHV environment.

The induced fields have strong dipole and sextupole components. An eddy current correction winding on the vacuum chamber is adopted to compensate sextupole and higher order multipoles[3]. This correction has three major advantages: 1) eliminate the systematic sextupole component right at the source and make the chromaticity control much easier, 2) because the correction coil is attached to vacuum chamber, the positioning of the vacuum chamber is not too critical, 3) because the correction is due to a transformer effect and requires no separate power supply, its correction is rate independent.

3.3 Orbit and Stopband Corrections. 24 BPMS and 24 horizontal correctors will be placed next to focusing quadrupoles for horizontal orbit correction. (Corresponding arrangement is also provided for vertical plane). Assuming RMS random field error of $\Delta B/B = 2x10^{-4}$, quadrupole misalignment of 0.2 mm, the maximum uncorrected orbit errors are about 10 mm in both planes which can be corrected to be about 0.5 mm using either three bumps method or harmonic correction method. The maximum corrector strength required is about 15 G-m.

The control of horizontal and vertical tune will be done through the QF and QD trim supplies. Every quadrupole will have an independent trim coil up to 1% of injection strength for 1/2 integer stopband correction. 24 skew quadrupole will be provided for correction of coupling resonance Qx-Qy=0 and Qx+Qy=9. 48 sextupoles are also pro-vided for chromaticity correction[4]. Every sextupole will have an independent trim coil up to 1% of injection strength for 1/3 integer stopband correction. If it is proven to be necessary, some of the sextupole will be rotated to provide skew sextupole for coupling resonance correction.

3.4 RF Capture and Beam Loading. After H^- injection into the Booster, a 2.2 MHz RF system has to be employed to capture 200 MeV linac beam with 200 MHz structure. We found that multiturn injection process is important with space charge effect, also capture at larger initial voltage is favorable instead of adiabatic capture. Optimal capture can be achieved with chopped beam and off-frequency capture[5].

A low energy chopper to eliminate unwanted beam close to unstable fixed points of capturing RF system serves many useful purposes. Getting rid of beam outside of the Booster improves the capture efficiency and minimize radiation loss in the ring. Furthermore, the chopper can control the bunch length and area effectively to improve the beam quality after capturing. To summarize, with RF voltage creating a bucket height 4 times the energy spread of the Linac beam, the capture efficiencies under different beam condition and capture modes are:

	Low Intensity	High Intensity
No Spacecharge	~ 95%	~ 85%
With Spacecharge	~ 80%	~ 65%
With S.C. and Chopper	~ 95%	~ 85%

A feedforward system will be applied to cancel the beam loading to keep external RF in proper amplitude and phase. When first pulse of Booster beam enters the AGS, a transient beam loading will occur which could cause up to 35% amplitude modulation and 20^o phase shift. The proposed solution for AGS RF System is to place the power amplifier next to the cavity and implement fast feedback at the final stage of the amplifier to eliminate the transient beam loading and reduce apparent impedance for the beam.

3.5 Power Grid Perturbation. The Booster will be energized from a feeder with the coupling node at the LILCO Brookhaven substation with a SCC of 2310 MVA. During proton operation the full energy swing is 22 MW which can produce both voltage and phase flicker on the power grid and could also introduce dynamic system oscillation or torsional oscillation of the generator. Both calculation and measurement showed that the voltage flicker is about 0.25% and that of phase flicker is about 0.7%. An extensive study was carried out by GE[6] to ascertain the effect on last two concerns. The results shows that certain frequency is to be avoided as shown in the response function in Figure 2. LILCO agreed to power the Booster provided: 1) a contract is signed to delineate operation condition, such as: power and frequency range, 2) a full power test before routine operation, 3) interlocks and monitors to prevent operation in forbidden frequency range.

3.6 Coherent Instabilities. Given the design intensity and beam emittances, calculation shows that it is still below the instability thresholds for both longitudinal and transverse single bunch instabilities. However, at Booster design intensity, the growth time results from resistive wall coupled bunch instability is around 3 msec which is fast enough to warrant a damping system[7].

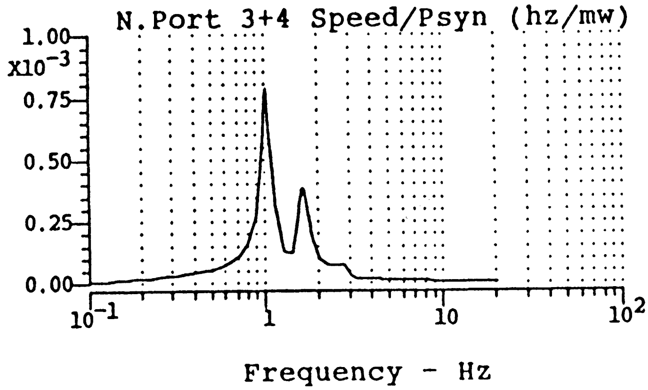

FIGURE 2 Frequency response of LILCO power grid.

Analysis is performed to understand the dependence of mechanism of instability threshold and growth rate on the space charge tune spread. We found that the space charge has the following effects on the coherent instability: a) the large capacitive impedance from the space charge tends to neutralize the sources of inductive impedances, such as bellows and discontinuities in the chamber cross-section, b) tune spread created by space charge contributes to the Landau damping of the instabilities, hence raises the threshold of critical intensity. However, it does not affect the growth rate once the instability occurs[8]. Expected total longitudinal impedance, including space charge, vacuum chambers, bellows, pick up electrodes, is shown in Figure 3[1]. Detailed analysis and measurement program is in progress to control impedances introduced by beam components, such as: BPM's, septum magnets, vacuum ports, RF cavities, etc.

In evaluating the kicker performance, we came upon an idea of reducing the coupling impedance of the ferrite kicker. The method is to break the flux path by inserting a copper sheet into the yoke of the magnet[9]. For our application, it not only eliminates the source of impedance, but also eliminates the flux heating of the ferrite due to beam induced flux in the ferrite. A test on our ferrite ring shows that the heating at full current and CW operation could be as high as 100°C above ambient temperature. The final temperature is dangerously close to the Carie temperature of the ferrite. By the copper sheet, both impedance and temperature problem have been successfully solved.

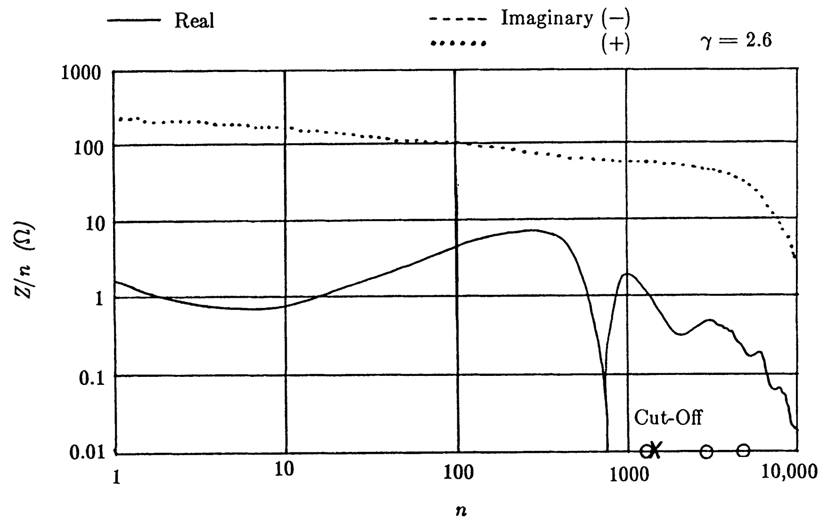

FIGURE 3 Z/n versus n for γ = 2.6

4. CONSTRUCTION STATUS AND SCHEDULE

Major construction-related works accomplished so far include the following. The conventional construction is 100% complete. Survey monuments have been placed on the floor to track the floor movement before magnet installation.

A half cell prototype assembly consisting of support base, dipole, quadrupole, sextupole, vacuum chamber and pump was assembled inside a section of mock-up tunnel. This exercise helped us to check space inside tunnel and in between magnets, assembly procedure and tooling, support and adjustment mechanism and the vacuum performance. A vacuum test on the half cell vacuum assembly succeeded in producing vacuum in the 10^{-11} Torr range. Half cell will be fully tested and precision-alligned for installation. As for now, all 36 bases are manufactured, 6 full dipoles and 4 completed quadrupoles have been assembled into the base. Tunnel installation of completed half cell units will start in October of 1989.

120 rings of Phillips 4M2 ferrite and 120 rings of TDK SY7 ferrite have been received. First RF cavity and power amplifier have been completed and tested with EIMAC tetrode tube 4CM 300,000G up to full design voltage of 80 kV. The controlling low level system with capability of radius and frequency control and synchronous transfer

from the Booster to the AGS is under construction.

A prototype beam position monitor (BPM) system and its measurement system have been constructed. The results of the linear response of the BPM satisfies the resolution requirements of 0.1 mm and range requirement of ± 3 cm. Good results were obtained after 900°C firing and repeatedly dismounted and reassembly. Delivery of vacuum chamber has started since April 1989. Major expenditure on power supply, control and instrumentation also takes place in FY 1989 and FY 1990.

Activities pertinent to the commissioning have been initiated. Those include system integration, installation plan and specifications for control algorithm and software. Installation is scheduled to complete in October 1990 and commissioning will immediately follow equipment test. Useful beam for proton physics can be expected in the Spring of 1991. Useful beam for heavy ion physics will be available in the Fall of 1991.

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