RESONANT EXTRACTION PARAMETERS FOR THE AGS BOOSTER *

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Abstract

Brookhaven's AGS Booster is the injector for the AGS. It is being modified to send resonant extracted heavy ions to a new beam line, the Booster Applications Facility (BAF). The design of the resonant extraction system for BAF was described in [1]. This note will give a more detailed description of the system and describe the predicted resonant beam time structure. We will describe tune space manipulations necessary to extract the resonant beam at the maximum Booster rigidity, schemes for performing resonant extraction, and describe the modifications required to perform bunched beam extraction to the BAF facility.

1 INTRODUCTION

The AGS Booster has operated since 1991 as an injector of protons and heavy ions into the AGS. The operating parameters are summarized in table 1. The Booster Application Facility (BAF) will employ heavy ion beams of many different ion species and at beam energies ranging from 0.04 to 3.07 GeV/nucleon. Resonant extraction is required in order to deliver a continuous stream of particles. In this report we describe the system and different possible modes of operation. The basic design is a third integer resonant extraction process which employs a single thin magnetic septum and a thick septum ejector magnet, with the error resonance created by re-configuring 4 of the main horizontal chromaticity sextupoles. The expected extraction efficiency is about 85 %, based on the thin septum thickness and the predicted step size of the resonant beam at the septum.

The maximum kinetic energy of the extracted beams corresponds to the maximum Booster rigidity of 17 Tm for the heavier ions, which are fully stripped at the stripping foil located at the entrance of the thick septum magnet, located in the Booster D6 straight section, and 13 Tm for lighter ions. The maximum rigidity of the BAF transport line is 13 Tm. Intensities of a few 10^8 down to 10^5 ions per pulse or less will be available to experimenters through collimation at the entrance to the D6 septum magnet.

2 NOMINAL MODE OF OPERATION

2.1 Standard Resonant Extraction for BAF

The Booster extraction system will make use of the horizontal third integer resonance at the tune of Q_h = 13/3. This tune is significantly lower than the nominal Booster tune, as shown in table 1. This is required because the Booster tune quadrupoles do not have enough strength to maintain the horizontal betatron tune at the value of 14/3 at the highest energies. To reach even 13/3 at 12 Tm a new power supply for the tune quadrupoles is needed. The required crossing of the half integer resonance at Q_h = 9/2 during acceleration is accomplished easily with the fast slew rate available from the tune quadrupole systems, which has been experimentally verified [4].

Table 1: AGS Booster Parameters

Parameter	Value
Circumference	201.78 (1/4 AGS) m
Ave. Radius	32.114 m
Magnetic Bend R	13.75099 m
Lattice Type	Separated Function, FODO
No. Superperiods	6
No. of Cells	24
Betatron Tunes,X,Y	4.82, 4.83
Vacuum Chamber	70 x 152 mm Dipoles
	152 mm (circular) Quads
Max. Rigidity	17 Tm
Injection Rigidity	2.2 Tm (200 MeV protons)
	0.9 Tm (1 MeV/nuc Au(32+))
Acceleration Rate	8.9 T/s up to 7.5 Tm (7.5 Hz)
	1 T/s up to 17 Tm (0.7 Hz)

A third integer resonance is excited by the 13^{th} harmonic of two sextupole pairs located at C8, F8, B4, and E4. We plan to utilize four of the existing 24 horizontal lattice sextupoles as drive sextupoles, which have sufficient strength. At the resonance, a stable triangular region of the horizontal phase space is defined within three linear separatrices and the area and orientation of this region can be controlled by the drive sextupoles. In the vicinity of the resonance there is a small range of tunes over which the separatrix degenerates into three narrow legs which have a phase advance of 2/3 π radian with respect to each other. A particle leaving the stable area within the separatrix moves out along one of these legs as it spirals out of the machine. This particle will move from one leg to the next every turn, each revolution stepping further out along the separatrix legs.

The thin septum is located in the downstream end of the D3 straight section (2.6 m) of the Booster. An angular kick from the thin septum translates into a large displacement at D6. This can be seen more clearly in figure 1 which shows the phase space separatrix and the extracted beam trajectory at the thick septum.

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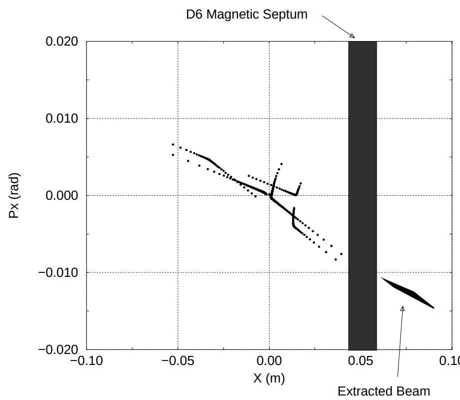

Figure 1: Resonant extraction phase space at the location of the thick septum for $\nu_{res} = 13/3$.

2.2 *Equilibrium Orbit Deformation at Septa*

Existing single turn auxiliary windings in the Booster Dipole magnets C7, D1, D4, D7 and E1 will be connected to provide local orbit bump control at D3 and D6. The D3 thin septum magnet will be movable over a small range, to allow maximizing the extraction efficiency for a given resonance step size. Figure 2 shows the design orbit bump and the location of the thin and thick septa.

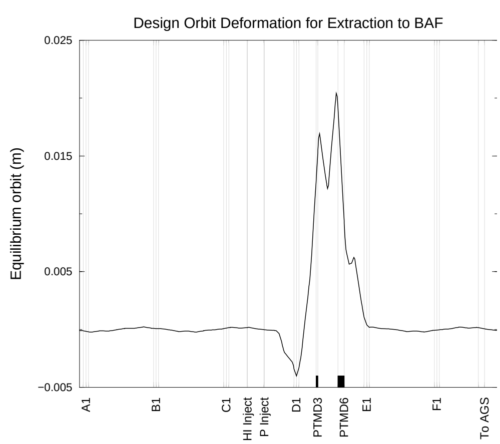

Figure 2: Orbit deformation at the thin and thick septa.

2.3 *Other Booster Modifications*

The design of the resonant extraction system requires some rearrangement of existing apparatus in the Booster. The most important changes are the addition of two new magnets. The D6 straight section will contain a new thick septum magnet, a stripping foil and flag (for beam profiles) mechanism, and a collimator. In addition we will modify the quarter cell vacuum chambers, shown in figure 3, to have a larger horizontal aperture. The vacuum chamber in the D4 half cell will be modified to be the same as DQ5. In the D3 straight section we will install a new thin septum magnet. Four of the horizontal chromaticity sextupoles will have new power supplies so that they may be used to create a sextupole resonance, as well as track the normal chromaticity system.

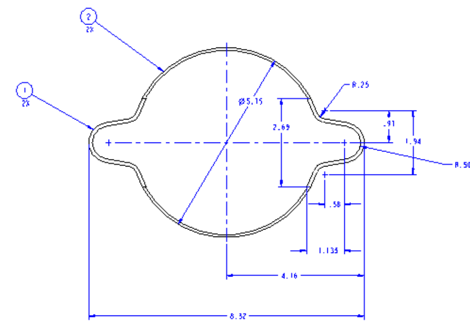

Figure 3: DQ3 and DQ5 Vacuum chambers cross section

2.4 *Thin and Thick Septum Designs*

Both the thin and thick septa must reside in the ultra-high Booster vacuum. All parts need to be able to take the high temperatures created during a vacuum baking process. The motor drives for the thin septum, the stripping foil at the entrance to the thick septum, and the collimator at the entrance to the thick septum have been designed given the vacuum system considerations. The designs must also provide very high reliability and have high radiation tolerance.

The thick septum magnet is designed as a sector magnet with four turn windings in the septum. There is significant saggita in the beam trajectory, since the beam has an entrance angle of the order of -12 mrad. To compensate for this the septum arc does not follow the arc of the beam, but is shallower, allowing the beam trajectory to move away from the septum as the beam is bent through the magnet.

3 EXTRACTION ON THE 1/2 INTEGER

Since the Booster tune quadrupoles are required to run at high currents, even to extract on the 13/3 resonance, we have investigated the possibility of extracting on the 9/2 resonance, using the sextupoles to create the resonance amplitude dependence (through second order moments). Figure 4 shows the phase space at the thin septum for 1/2 integer resonant extraction. Simply by reversing the polarity of one of the drive sextupole power supplies (which are bipolar), we can create an amplitude dependence at the 1/2 integer resonance. We are investigating this further, also looking at whether existing octupoles can be employed (although they are relatively weak).

4 EXTRACTING FAST BEAM INTO BAF

The Booster has a full aperture kicker that is utilized to kick bunches into a thick septum magnet, for transferring beam from the Booster to the AGS. This kicker magnet

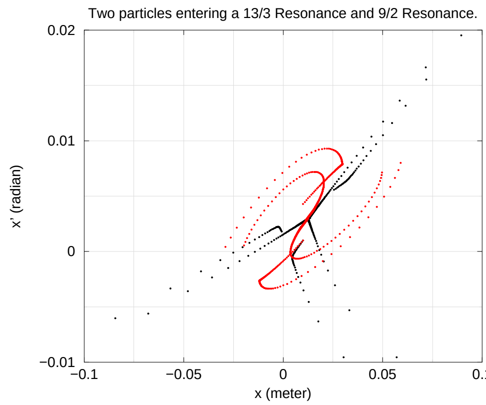

Figure 4: phase space at D3 for 1/2 and 1/3 integer resonant extraction

could be utilized to kick fast beam into the BAF beam line, if desired. Figure 5 shows the amount of displacement of the central trajectory at the thin and thick septa due to a 2 mrad kick from the F3 full aperture kicker as a function of horizontal betatron tune, at the maximum Booster rigidity.

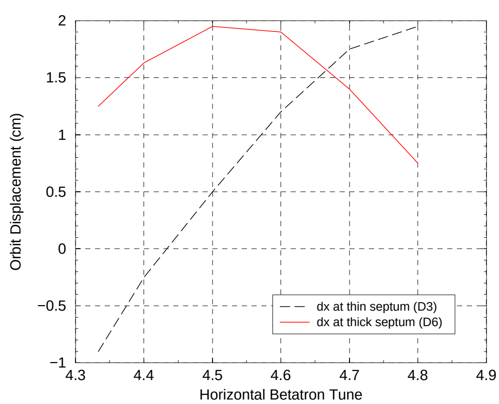

Figure 5: Displacement at thin and thick septa versus tune, for a 2 mrad kick from the F3 kicker, at $B\rho$=17 Tm.

5 SPILL STRUCTURE

Spill structure is created by variations in the rate at which particles move into resonance.

$$S(t) = \frac{dN}{dQ}(\dot{Q}_0 + \dot{Q}_v) \qquad (1)$$

where,

$$\dot{Q}_v = \frac{Q\xi}{I_m L_m}\sum_h V_h \qquad (2)$$

L_m is the total inductance of the main dipoles and quadrupoles and V_h is the sum of the 60 Hz harmonics amplitudes (in volts). $\dot{Q}_0$ is the rate at which the particles are moved into the resonance, Q is the nominal betatron tune, ξ is the lattice chromaticity, and $\frac{dN}{dQ}$ is the distribution of particles in tune space. $\dot{Q}_0$ will be controlled through the use of a low frequency feedback system, as described in [1].

Given, the beam size at full energy is about 1 cm, the maximum dispersion is about 3 m, and the chromaticity at extraction will be about -2, the maximum dp/p is about 1 % and the maximum dQ/Q is about -0.02. In this case $dQ \leq 0.09$.

There are two competing components to the spill structure.

$$\dot{Q}_0 = \frac{Q\xi}{I_m}\frac{dI_m}{dt} \qquad (3)$$

and $\dot{Q}_v$ [Eq. 2].

For a 1 second spill we expect $\dot{Q}_0$ to be -0.09 and, $\dot{Q}_v = -0.0119\sum_h V_h$.

The "best" we can do is approximately $\sum_h V_h = 18$ volts, in which case $\dot{Q}_v = -0.214$.

The result is a fully modulated beam spill for a 1 second beam. For 500 ms it will still be fully modulated. For the types of experiments being conducted at the BAF facility, this is not considered a problem. Nevertheless we are working to minimize the structure and it is possible to further reduce it in the future, through the addition of a high frequency rf cavity. Such a system has been used successfully in the AGS and at CERN. Currently we plan to only incorporate a system using high frequency feedback to the tune quadrupoles, which has been used successfully at BNL, CERN, and KEK.

6 CONCLUSIONS

The BAF facility construction is well under way and we will begin commissioning in FY03. Brookhaven's AGS Booster is proving to be a very versatile accelerator allowing for many different modes of operation.

7 REFERENCES

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