R-MATRICES OF THE FAST BEAM EXTRACTION LINE OF AGS*

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Abstract

The Fast Beam Extraction (FEB) system of the Alternating Gradient synchrotron (AGS) extracts the beam bunches from AGS into the AGS-to-RHIC (AtR) beam transfer line, which injects the beam bunches into the Relativistic Heavy Ion Collider (RHIC). As the beam bunches are extracted from the AGS, they are transported through the fringe field region of three main magnets of the AGS. The optical characteristics of this section of the extraction line depend on the trajectory and momentum of the beam, therefore the calculations of the R-matrices in this part of the extraction line requires special attention. To describe accurately the R-matrices of the extraction region along the fringe field of the AGS main magnets, the magnetic field of the AGS main magnets was measured on the median plane, in a) the fringe field region, where the extracted beam is transported, and b) in the circulating beam region. Using these magnetic field maps, we calculate the R-matrices at the beam extraction region for any settings of the AGS. These R-matrices are used to calculate the beam parameters at the starting point of the AtR beam transfer line and subsequently to calculate the required quadrupole settings of the AtR line, to match RHIC's acceptance. In this paper we describe a) the FEB system of the AGS b) the method to calculate the R-matrices in the extraction region along the fringe field, and c) provide an example of the AtR line model which includes the calculated R-matrices.

THE FAST EXTRACTION BEAM IN AGS

The FEB extraction system of the AGS is shown schematically in Fig. 1. It consists of two local beam bumps (green lines in Fig. 1) which are excited just before beam extraction; one beam bump, ”G10-bump” displaces the beam inside a C-type kicker “G10” and the other bump ”H10-bump” displaces the beam near the extraction septum “H10” which is located at a phase advance of 260^o downstream of the G10 kicker. When the “G10” kicker is excited, it ”kicks” a bunch (red line in Fig. 1) which enters the main field region of the “H10” extraction septum that extracts the beam into the AtR transfer line. This paper presents a model of the “AGS-AtR” transfer line. For convenience the “AGS-AtR” line is partitioned in three sections, first, the ”FEB” section which starts at the G10-kicker and ends just before the H10-septum (see Figure 1), second, the Fringe Field Region ”FFR” section which starts at the H10-septum, includes the fringe field of three AGS magnets, and ends at the beginning of the AtR line, and

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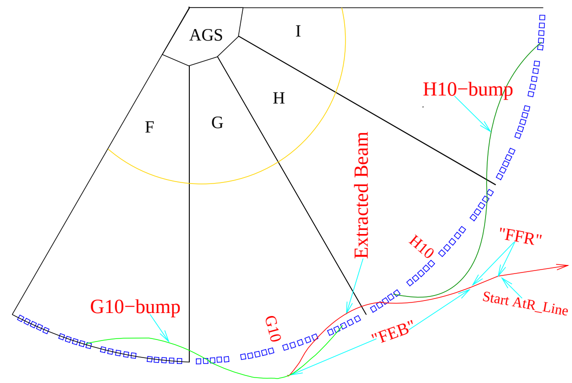

Figure 1: Diagram of the FEB section in AGS. The small blue squares are the AGS main magnets, the green lines correspond to the local beam bumps (see text). The red line is the extracted beam trajectory.

third section, the AtR line which ends at the RHIC injection point. This ”three-section” beam transfer line that includes the G10-kicker and the H10-septum can be used in the beam-diagnostics application of the transfer line to help determine the effect on the beam from the instabilities of the extraction devices (beam-bumps, G10-kicker and H10-septum). Details on the AGS-FEB system can be found in Refs. [1] and [2].

METHOD TO COMPUTE R-MATRICES OF THE “FEB” AND ”FFR” SECTIONS

In this section we describe, in brief, the proccedure [2] to calculate the R-matrices of the “FEB” and “FFR” beam line sections. All calculations are based on raytracing particles in the field maps of the main magnets of the AGS. The field maps were performed [3] over a grid coinciding with the median plane of the AGS main magnets. The grid extends, to include the fring field regions of the main magnets where the extracted beam is passing. The magnets were also mapped as a function of excitation current, choosing steps to provide accurate description of the magnet's field at any other excitation current, when using linear interpolation of the experimental fields. In the rest of the section we desribe the main steps that are followed to calculate of the R-matrices in the two beam extraction sections, “FEB” and ”FFR”. These steps are: a) Fit the experimental data of the discrete field map using a polynomial. b) Using Maxwell equations we calculated the components of the B-field off the median at any point along the orbit of a particle in the beam. c) The fields in steps (a) and/or (b) are utilized by modified raytrace codes [4], [5], to close the beam orbit in AGS just before extraction with the extraction beam bumps

"G10-bump" and "H10-bump" excited. After closing the orbit, the beam parameters $\beta_{x,y}, \alpha_{x,y}$ and dispersion functions $\eta_{x,y}, \eta^{'}_{x,y}$ are calculated at the location of the G10 kicker just before extraction. d) The G10 kicker is excited to extract the beam from the AGS. e) By raytracing the extracted orbit, the R-matrices from the location G10 to H10 ("FEB" section) and from H10 to the Starting point of the AtR line ("FFR" section') are calculated. During raytracing, the "tune quadrupoles" and "chromaticity" sextupoles, of the AGS, if excited, are treared as thin elements in the raytrace code BEAM++ [4] and as thick elements with fring fields in the code RAYTRACE [5].

THE "AGS-ATR" LINE

The model of the beam transfer line from AGS to RHIC can be considered made of three line sections:

{"AGS-AtR"} = {"FEB" + "FFR" + "AtR-line"} The "FEB" and "FFR" sections which are represented by a single R-matrix each, are included in the model of the "AGS-AtR" transfer line for a complete description of the line's optics. In this section we present the beam optics of this transfer line and we discuss some the benefits obtained from the use of a complete line.

The calculated R-matrix elements which describe the "FEB" and "FFR" sections are printed below.

$$\begin{pmatrix} -1.8261 & -17.443 & 0.0000 & 0.0000 & 0 & -2.5889 \\ 0.17912 & 1.1634 & 0.0000 & 0.0000 & 0 & 0.2517 \\ 0.0000 & 0.0000 & 1.12425 & -15.016 & 0 & 0.0000 \\ 0.0000 & 0.0000 & 0.18951 & -1.4855 & 0 & 0.0000 \\ -0.0041 & 1.3785 & 0.0000 & 0.0000 & 1 & 0.000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0 & 1.0000 \end{pmatrix} \quad (1)$$

$$\begin{pmatrix} 2.2886 & 14.523 & 0.0000 & 0.0000 & 0 & 0.1566 \\ 0.26387 & 2.1114 & 0.0000 & 0.0000 & 0 & 0.0156 \\ 0.0000 & 0.0000 & 0.050902 & 6.2687 & 0 & 0.0000 \\ 0.0000 & 0.0000 & -0.15730 & 0.19950 & 0 & 0.0000 \\ 0.0056 & 0.1041 & 0.0000 & 0.0000 & 1 & 0.000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0 & 1.0000 \end{pmatrix} \quad (2)$$

The matrix elements of the the "FEB" section depend on, a) the field of the AGS main magnets, b) the settings of the tune quadrupoles and chromaticity sextupoles, and c) the beam radius at extraction. In contrast the matrix elements of the "FFR-section" have a rather weak dependance on the excitation field of the main magnet, and this is due to the linearity of the field with the excitation of the main magnet. The "AtR" section of the line, which consists of dipole and quadrupole elements, is modelled with the MAD code.

"AGS-AtR" for Au^{+79} Ions Transported to RHIC

As mentioned earlier, the beam parameters $\beta_{x,y}$, $\alpha_{x,y}$ and dispersion functions $\eta_{x,y}$, $\eta^{'}_{x,y}$ are calculated at the location of the G10 kicker, which is defined in this paper as the starting point of the "AGS-AtR" line, just before extraction. These beam parameters are used in the "AGS-AtR" beam line and the beam optics of the line is calculated by imposing the various conditions that the transfer line should satisfy [7]. The beam parameters $\beta_{x,y}$, $\alpha_{x,y}$ and dispersion functions $\eta_{x,y}$, $\eta^{'}_{x,y}$ along the line are ploted in Fig. 2. Note that in some sections along the line the beam is constrained to be achromatic ($\eta_{x,y}$=0, $\eta^{'}_{x,y}$=0), and in other sections to be matched to a FODO lattice. The small blue boxes shown in Fig. 1 are the dipoles and quadrupoles of the "AtR" line. Note also that the first 75 m of the line does not contain elements because this part of the line is described by the "FEB" and "FFR" transfer R-matrices. The

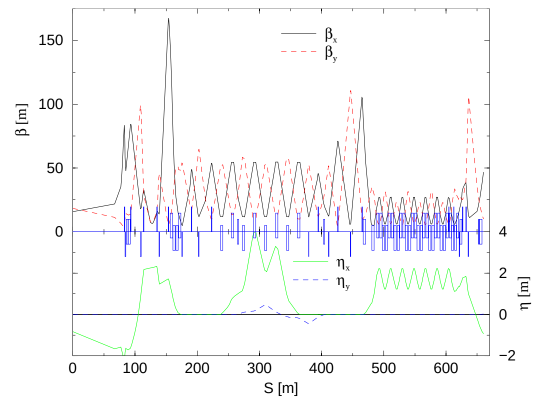

Figure 2: $\beta_{x,y}, \alpha_{x,y}$ and $\eta_{x,y}, \eta^{'}_{x,y}$ in the "AGS-AtR" line.

calculated beam parameters at the beginning of the "AGS-AtR" line which is the center of the G10-kicker, are shown in Table 2. and correspond to beam rigidity 88.233 [T.m] for Au^{+77} extracted from the AGS synchrotron at a radius of 4.9 [mm]. The tune quadrupoles and chromaticity sextupoles were excited during extraction.

Table 1: Beam Parameters, and Dispersion

β_x[m]	α_x	η_x[m]	$\eta^{'}_x$	β_y[m]	α_y
15.73	1.29	-0.835	0.034	18.21	-1.64

Effect of G10-kicker and H10-septum Errors on the Beam Trajectory

Under normal beam extraction conditions the G10-kicker and H10-septum are excited to align the extracted beam trajectory along the optic axis of the transport line. Field and timing errors of these two extraction devices may cause the central trajectory of the beam to deviate from the optic axis of the line. Such a deviation of the trajectory (X_{cod}) is detected by the Beam Position Monitors (BPM) of the line and the beam diagnostics software can detect the origin of the error. The central orbit displacements (X_{cod}) along the "AtR" line, as calculated by using an error of 0.5 [mrad] in the strength of the G10-kicker or the H10-setum are plotted in Fig. 3. In Fig 3 the values of the (X_{cod}) and $\eta_{x,y}$ functions which correspond to 0.5 [mrad] error in G10-kicker are the black and green lines. The corresponding quantities for error of 0.5 [mrad] in the H10-septum are the red and blue dashed lines. Fig. 4 is similar to Fig. 3 but

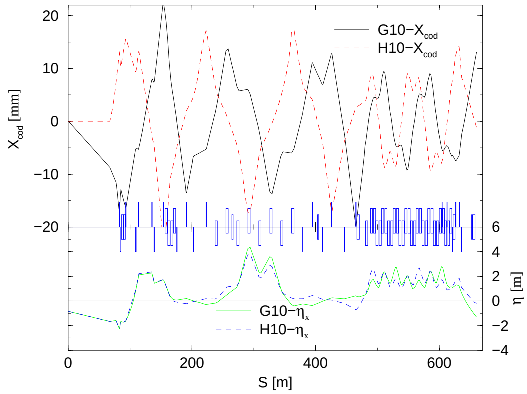

Figure 3: The X_{cod} and $\eta_{x,y}$ in the "AGS-AtR" line. The G10-kicker has 0.5 [mrad] error(black, and green) or the H10-septum has +0.5 [mrad] error (red, and blue dashed).

the X_{cod} and dispersion functions $\eta_{x,y}$ which are plotted along the line are due to +0.5 [mrad] error in the stregth of both the G1–kicker and H10-septum.

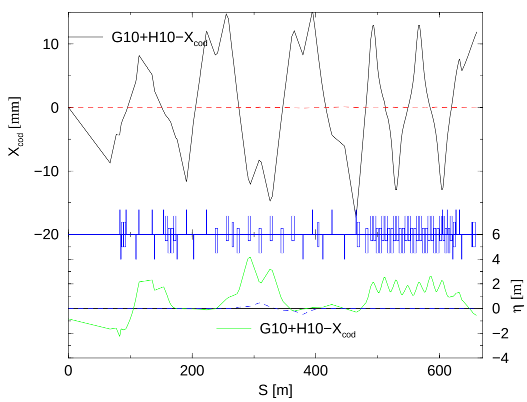

Figure 4: Same as in Fig. 3 but the plotted beam displacement X_{cod} and dispersion functions $\eta_{x,y}$ (black, and green lines) along the "AGS-AtR" line are due to a simultaneous error of G10-kicker and H10-septum of +0.5 [mrad] each.

THE "FEB" LINE USING MAD MODEL

In the previous section we described the "FEB" line with a single R-matrix which was calculated by raytracing the particles in the measured magnetic field. Since the "FEB" line is comprised of lump magnetic elements, it can also be desribed using a MAD-based model. The R-matrices of the combined function magnets of the AGS have been calculated on the basis of the experimental magnetic field maps which were mentioned ealrier. Fig. 5 shows the beam parameters $\beta_{x,y}$, $\alpha_{x,y}$ and dispersion functions $\eta_{x,y}$, $\eta'_{x,y}$ along the line. Table 2 contains the values of $\beta_{x,y}$, $\alpha_{x,y}$ and $\eta_{x,y}$, $\eta'_{x,y}$ at "G10" and "H10" locationsas as calculated with the MAD and RAYTRACE codes. These values as well as tunes and chromaticities are to be compared [6] with the experimental measurements to improve the theoretical models.

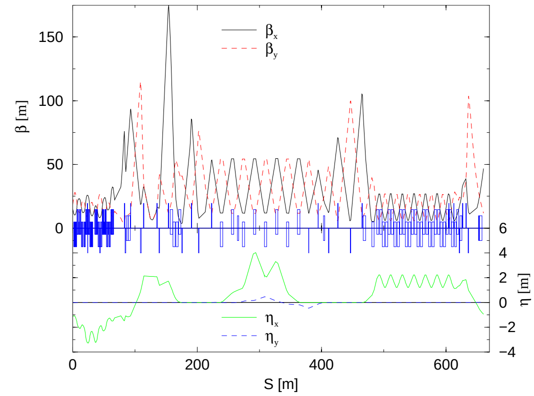

Figure 5: Beam parameters $\beta_{x,y}$, $\alpha_{x,y}$ and dispersion functions $\eta_{x,y}$, $\eta'_{x,y}$ along the "AGS-AtR" line. The parameters of the "FEB" line have been calculated using a MAD model of the line (see text).

Table 2: Comparison of MAD and RAYTRACE of $\beta_{x,y}$, $\alpha_{x,y}$ and $\eta_{x,y}$, $\eta'_{x,y}$ at locations "G10" and "H10".

Location	β_x[m]	α_x	η_x[m]	η'_x	β_y[m]	α_y
MAD-G10	14.98	1.25	-1.133	0.046	18.50	-1.74
RAY-G10	15.73	1.29	-0.835	0.034	18.21	-1.64
MAD-H10	22.14	1.94	-1.238	0.111	13.26	-1.16
RAY-H10	21.86	1.82	-1.657	0.142	12.60	-1.11

CONCLUSIONS

The R-matrices of the AGS Extraction line can be calculated for any extraction setup of the AGS. These matrices integrate the AtR line to the AGS synchrotron and make it possible to determine the effect of the AGS extraction devices on the trajectory of the beam along the AtR line.

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