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MODEL DRIVEN RAMP CONTROL AT RHIC*

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Abstract

At the Relativistic Heavy Ion Collider (RHIC), magnets are ramped from injection energy to storage energy in several minutes where it is to remain for several hours. The path up the ramp is marked by 'StepStones' where the the optics of the machine, which can change dramatically when we perform a beta*-squeeze, is given in units like quadrupole focusing strengths or corrector-dipole angles. The machine is tuned at these Stepstones, and at injection or storage, by specifying physics properties like tunes and chromaticities. An on-line model server handles conversion to magnet strengths, and predicts the optics along the whole ramp.

We will describe the underlying principles, the client-server environment, including on-line model servers, Ramp Manager and Editor, and present operational experience with the system.

1 INTRODUCTION

The RHIC magnets are driven by about 1000 Wave Form Generators (WFG). Most quadrupole magnets are hooked up through a nested power supply scheme, which minimizes the number of high current cryogenic feed-throughs, but complicates their programming considerably. A more detailed description of the ramp control is given in [1], here we concentrate on the physics control and modeling sections.

2 MAGNET CONTROL

Magnets are programmed in physics units like KL (integrated strength), and angle. The WFG's execute formulas at 720Hz that read the machine magnetic rigidity from the real time data link (RTDL), look up the interpolated requested magnet strength, calculate the required field strength, and use the magnetic transfer table to calculate currents for the associated power-supplies.

2.1 StepStones

StepStones are placeholders for a set of magnets and their associated strengths. The strengths is split up in a 'Design', and 'Trim' part. The machine is set to the design level by modifying the trim settings, client applications usually use the design part of the strength for model calculations, since it more closely resembles the real machine. StepStones are sparse, in a sense that only some magnets need to be set explicitly, all other are interpolated as a function of the relativistic gamma. The interpolation scheme is critical for proper power supply performance, and involves cubic splines for quadrupole and sextupole magnet strengths. Other types of magnets use linear interpolation of strengths.

2.2 Ramps

Ramps are placeholders for a set of StepStones. The ramps in use at the moment for RHIC accelerate, and Beta*-squeeze at the same time. The model server does optics simulations at many points along the ramp, giving tunes and chromaticity predictions that can be compared with measured numbers. The model can contain multiple named ramps simultaneously, each containing tens of StepStones (see Fig. 1 for a typical ramp layout, Fig. 2 for a graph of the main quadrupole strength).

3 MODEL SERVERS

Multiple model servers are available, each presenting an identical interface. The differences are in speed and accuracy. The fast model only considers linear un-coupled optics. There are on-line models available which consider full coupling, non-linearities etc. [2], but with the associated longer execution time. For regular machine operation the linear model is preferred, for studies we can switch to a more complete model.

The model server is implemented using the CDEV [3, 4, 5] generic server framework, which allows for rich data structures to be passed between client and server. Ramps and StepStones are accessible as CDEV devices, and present properties which can be monitored by the client applications. The clients receive updates when magnet strengths are modified. All typical optics properties are exported, the most commonly used ones include:

- 'LatticeFunctions', the clients specify a beam line (Blue or Yellow) and a list of element names. The server by default returns a full set of lattice functions. The context can be modified to only request certain lattice functions.
- 'OpticsFunctions', the clients specify a beam line. The server returns a list of tunes, chromaticities, etc.

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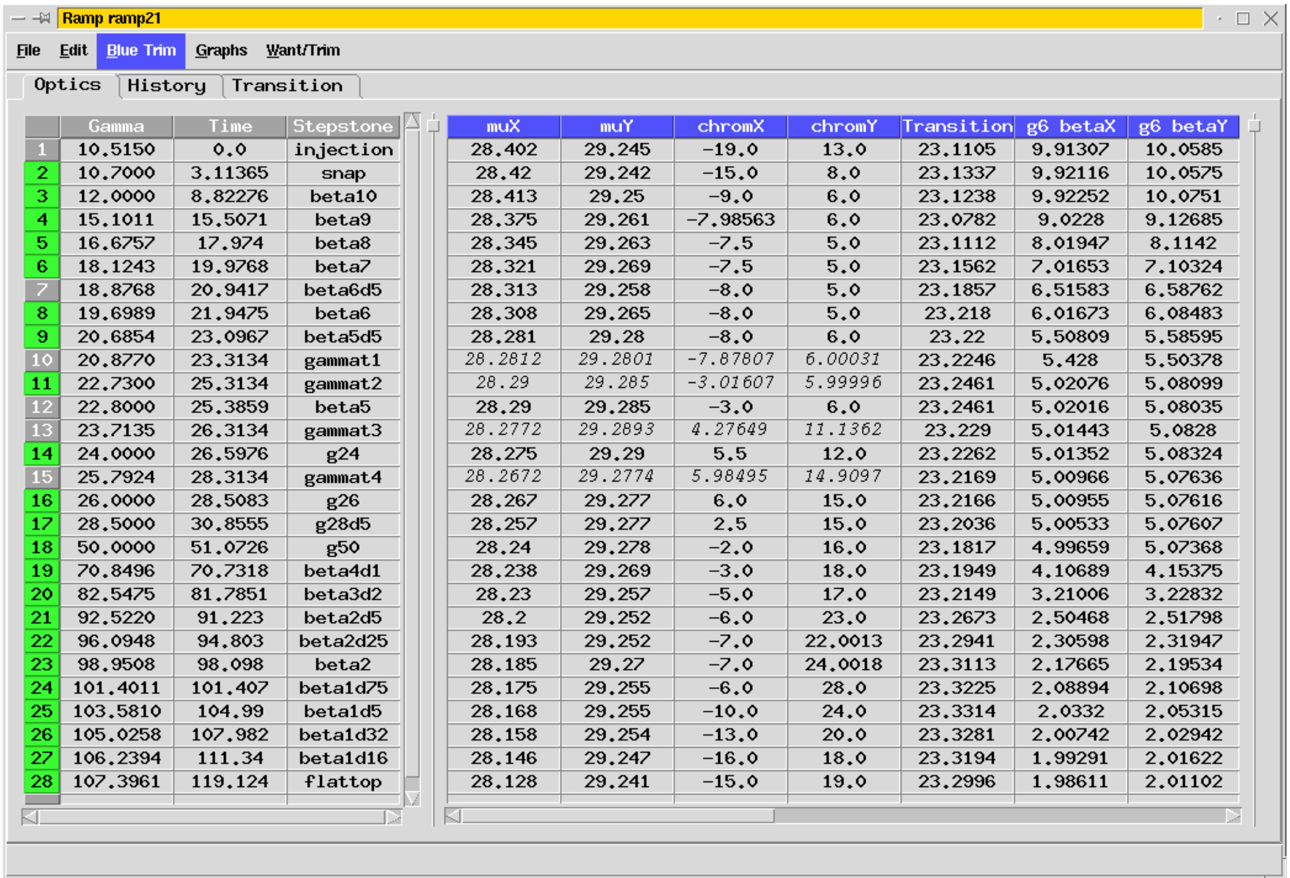
Ramp ramp21
File Edit Blue Trim Graphs Want/Trim
Optics History Transition

	Gamma	Time	Stepstone	muX	muY	chromX	chromY	Transition	g6 betaX	g6 betaY
1	10.5150	0.0	injection	28.402	29.245	-19.0	13.0	23.1105	9.91307	10.0585
2	10.7000	3.11365	snap	28.42	29.242	-15.0	8.0	23.1337	9.92116	10.0575
3	12.0000	8.82276	beta10	28.413	29.25	-9.0	6.0	23.1238	9.92252	10.0751
4	15.1011	15.5071	beta9	28.375	29.261	-7.98563	6.0	23.0782	9.0228	9.12685
5	16.6757	17.974	beta8	28.345	29.263	-7.5	5.0	23.1112	8.01947	8.1142
6	18.1243	19.9768	beta7	28.321	29.269	-7.5	5.0	23.1562	7.01653	7.10324
7	18.8768	20.9417	beta6d5	28.313	29.258	-8.0	5.0	23.1857	6.51583	6.58762
8	19.6989	21.9475	beta6	28.308	29.265	-8.0	5.0	23.218	6.01673	6.08483
9	20.6854	23.0967	beta5d5	28.281	29.28	-8.0	6.0	23.22	5.50809	5.58595
10	20.8770	23.3134	gammat1	28.2812	29.2801	-7.87807	6.00031	23.2246	5.428	5.50378
11	22.7300	25.3134	gammat2	28.29	29.285	-3.01607	5.99996	23.2461	5.02076	5.08099
12	22.8000	25.3859	beta5	28.29	29.285	-3.0	6.0	23.2461	5.02016	5.08035
13	23.7135	26.3134	gammat3	28.2772	29.2893	4.27649	11.1362	23.229	5.01443	5.0828
14	24.0000	26.5976	g24	28.275	29.29	5.5	12.0	23.2262	5.01352	5.08324
15	25.7924	28.3134	gammat4	28.2672	29.2774	5.98495	14.9097	23.2169	5.00966	5.07636
16	26.0000	28.5083	g26	28.267	29.277	6.0	15.0	23.2166	5.00955	5.07616
17	28.5000	30.8555	g28d5	28.257	29.277	2.5	15.0	23.2036	5.00533	5.07607
18	50.0000	51.0726	g50	28.24	29.278	-2.0	16.0	23.1817	4.99659	5.07368
19	70.8496	70.7318	beta4d1	28.238	29.269	-3.0	18.0	23.1949	4.10689	4.15375
20	82.5475	81.7851	beta3d2	28.23	29.257	-5.0	17.0	23.2149	3.21006	3.22832
21	92.5220	91.223	beta2d5	28.2	29.252	-6.0	23.0	23.2673	2.50468	2.51798
22	96.0948	94.803	beta2d25	28.193	29.252	-7.0	22.0013	23.2941	2.30598	2.31947
23	98.9508	98.098	beta2	28.185	29.27	-7.0	24.0018	23.3113	2.17665	2.19534
24	101.4011	101.407	beta1d75	28.175	29.255	-6.0	28.0	23.3225	2.08894	2.10698
25	103.5810	104.99	beta1d5	28.168	29.255	-10.0	24.0	23.3314	2.0332	2.05315
26	105.0258	107.982	beta1d32	28.158	29.254	-13.0	20.0	23.3281	2.00742	2.02942
27	106.2394	111.34	beta1d16	28.146	29.247	-16.0	18.0	23.3194	1.99291	2.01622
28	107.3961	119.124	flattop	28.128	29.241	-15.0	19.0	23.2996	1.98611	2.01102

Figure 1: High-level display of a ramp in the Ramp-Editor. Tunes and Chromaticities are modified from this page.

- 'Orbit', the clients specify a beam line, and a list of element names. The server returns the predicted orbit using the dipole corrector set points.

4 CLIENT APPLICATIONS

The on-line model server is the hub for lattice and optics information. Magnetic element strength are handled in a separate Ramp-Manager. Applications routinely retrieve and monitor element strengths and lattice functions at specific StepStones, and (at a higher resolution) along the ramp. Below is a subset listed of the client applications connected to the model.

4.1 Ramp Editor

The main ramp control GUI allows modification to tunes, chromaticities, and individual element strengths. On each change the model recalculates the predicted optics at each stone, and along the ramp.

4.2 Injection Application

Injection into both the RHIC rings is facilitated by the 'Injection Application'. This application retrieves the transverse lattice functions in the transfer line and the first sextant of the rings from the model server. Dipole corrections for optimized injection, and closed orbits are calculated and sent to the Ramp Manager. Predicted and measured orbits are displayed.

4.3 Orbit Correction

Global Ring Orbit-Correction, Local Correction, 3 and 4 Bump construction etc. are supported in this application. Dipole correctors strengths are calculated and set though this application. Lattice function information, including phase advance between correctors and Beam Position Monitors (BPM) is retrieved from the model. Predicted and measured orbits are displayed.

4.4 Transverse Profile Manager

Lattice functions at the Profile pickups are monitored by the 'Profile-Manager', measured profiles are then converted to normalized emittance at injection, up the ramp, and at storage energies.

4.5 Luminosity Monitor

Beta functions at the interaction regions are monitored by the 'Luminosity-Monitor', which combines this information with beam intensity and compares measured and predicted luminosity.

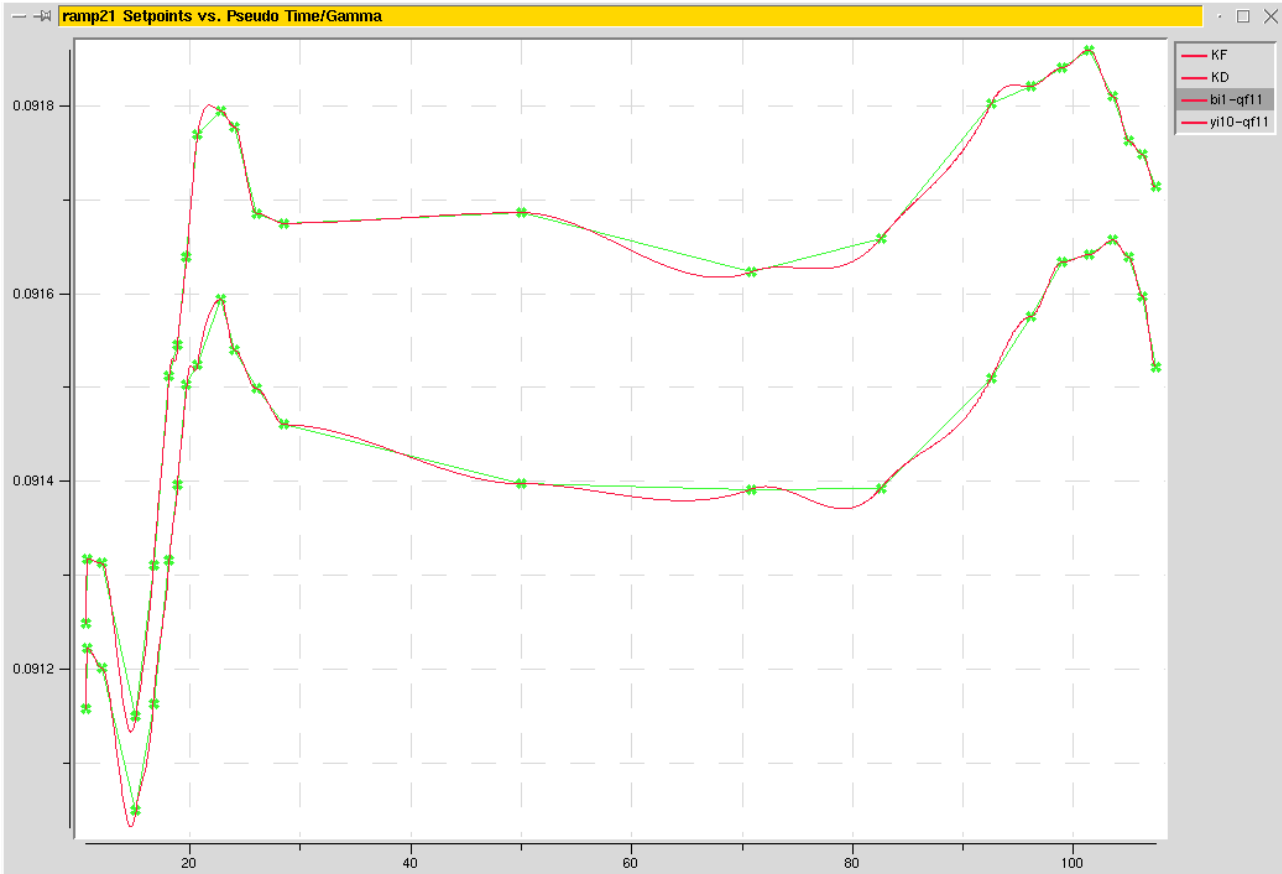

Figure 2: Main quadrupole magnet strength vs. gamma. The green markers are at the location of the StepStones, the smooth lines are the cubic-spline interpolation.

4.6 Coupling-Correction Application

In order to correct transverse coupling in the machine the tune set-points are swept over a given range while plotting the measured tunes vs. set-points. The correction application utilizes the model to calculate the required set points.

4.7 Sequencer

Progress though the many steps required to run the RHIC through its machine cycle is choreographed by the 'Sequencer' program [6, 7]. This program sets the 'liveRamp' and 'liveStone' CDEV devices to their appropriate value during the cycle. The client applications usually use these aliases to get updates on the current optics, instead of named stepstones.

5 OPERATIONAL EXPERIENCE

Having a consistent source of optics information is critical for commissioning a complex machine. The on-line model servers provide such a source. The servers have been in operational use for several years serving client applications routinely used to run the machine. The interface to the servers is through a well defined CDEV interface, which much simplifies the client application programming. The system of servers is flexible, and performs reliably even under simultaneous load of tens of client applications.

6 REFERENCES

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