NSLS-II BOOSTER RAMP HANDLING

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Abstract

The NSLS-II booster [1] is a full-energy synchrotron with the range from 200 MeV up to 3 GeV. The duration of ramping cycle is 1 or 0.5 second. A set of electronics [2] developed in BNL for the NSLS-II project was modified for the booster Power Supplies (PSs) control. The set includes a Power Supply Interface (PSI) which is located close to a PS and a Power Supply Controller (PSC) which is connected via 100 Mbit Ethernet to EPICS IOC running in a front-end computer. A sequence of 10k setpoints (ramp waveform) uploaded to the memory of PSC defines behaviour of the PS in the machine cycle. Special functions are implemented in the IOC to check a smooth shape of the ramping waveform. Ramp Manager (RM) high level application written in Python is developed to provide an easy changing, comparing, copying the ramping waveforms, and uploading them to the IOC. RM provides check of a waveform derivative, manual adjusting of the waveform in graph and text format, and covers specific features of the booster PSs control. This paper describes tools for the booster ramp handling.

INTRODUCTION

The control of the booster cycle is based on use of the ramp waveform of 10k setpoints through 100 usec which is implemented as a waveform process variable (PV) in EPICS IOC. The cycle start event coming from the NSLS-II timing system [3] trigger all PSCs to perform the uploaded ramp waveforms.

The beam ramping in the booster is provided by synchronous change of magnetic fields in dipoles (three serially connected sets of magnets) and quadrupoles (also three serially connected sets of magnets) and voltage in RF cavities. The ramping time is about 300 ms (see Fig. 1).

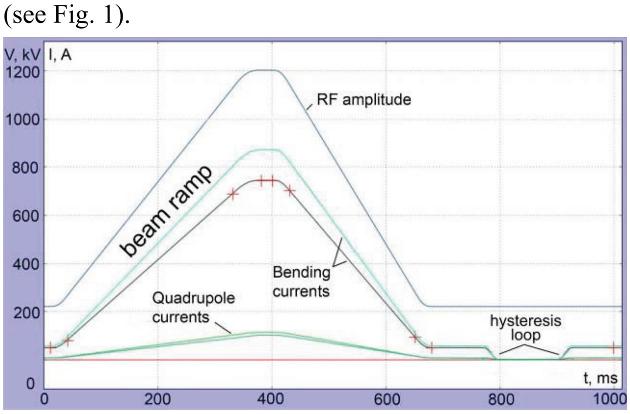

Figure 1: Ramping curves for main magnets and RF in 1 Hz cycle mode.

The setpoint ramping waveforms of magnetic elements should match each other with relative accuracy of 10^{-3} during the beam ramp. Dipole and quadrupole PSs require very smooth shape of curves without jumps of the fist and the second derivatives. The RF amplitude setpoint waveform also should follow the shape of the dipole ramping curve.

Final checking of the ramp waveform before the uploading to PSC is automatically performed in PS IOC [4]. Forming of the shape of PSs control signal and initial checking of the signal are performed with a help of RM tool which has two modes of the ramp waveform edition: linear interpolation between nodes and polynomial.

The beam injection and extraction are provided by the pulsed elements: septum magnets and injection and extraction “fast” kicker magnets. The injection septum and kickers are specified to operate in a double injection (stacking) mode in 100 ms interval. Use of the 10k setpoint waveform provides a flexible control of the reference for the each shot. Additional features are implemented in RM to provide a required accuracy for operation of the pulsed elements in the stacking mode: RM applies some feed forward reference voltage for charging devices before the second shot.

Another feature of the booster control is a procedure of amplitude and phase reference voltages uploading to the booster RF system. This procedure requires a sequence of operations which is implemented as a script in RM.

CHECK FUNCTIONS IN POWER SUPPLY IOC

Before uploading to PSC the sequence of checking operations are performed in IOC with 10k setpoint waveforms for each point:

- All values should be in the limits of PSI output voltage -10 … +10 V for bipolar mode of the PSI, and 0 – 10 V for unipolar mode; IOC reads the PSI polarity before this check procedure.
- Each voltage step for each 100 us time step (first derivative: $abs(f(x_i)-f(x_{i-1}))$ should be less than tolerable step Δ_1 for correspondent type of PS.
- A difference between sequential differences for each 100 us time step (second derivative: $abs(f(x_i)-f(x_{i-1})-f(x_{i+1})-f(x_i))$ should be less than tolerable difference Δ_2 for correspondent type of PS.
- The first and the last values (end points) in the waveform should be equal.

Then the new waveform is compared with uploaded waveform. In case of high-energy PSs (dipoles and quadrupoles) if the first point of the new waveform differs from the last point of uploaded waveform more than Δ_1

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then an additional transition waveform will be automatically generated (see Fig. 2).

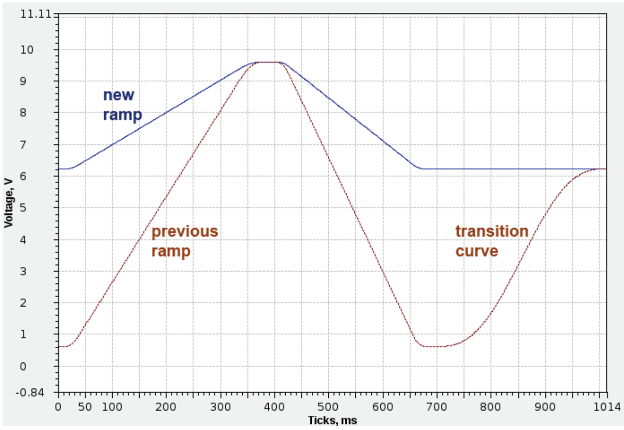

Figure 2: Ramping waveforms with the transition waveform (brown).

A transition curve in the transition waveform starts from the defined point of the uploaded waveform and it is calculated by IOC as a 5-degree polynomial. Transition curve has the first value, first and second derivatives equal to the values of the start point of the uploaded waveform, the same is for the first point of the new waveform. The transition waveform is performed once before performing of the new waveform. This operation is provided by PSC firmware.

In case of low-energy PSs for sextupoles and correctors the transition waveform is not used.

RAMP MANAGER FUNCTIONALITY

RM is a GUI application which includes a wide set of operations with ramp waveforms and sets of ramp waveforms. RM is developed in Python using matplotlib, so it has good possibilities for graphical edition and observation of setpoint and readback waveforms.

Screen General View

The general view of RM screen is presented in Fig. 3. The screen divided into several sections:

- Section for the element selection; this section allows operator to select a group of elements, then select an element from the group (marked 1 in Fig. 3).
- Section for ramping waveform text edition (marked 2 in Fig. 3); this section provides possibility to edit the ramping waveform table: input step points and values in the linear interpolation mode, or input coefficients in the polynomial mode (as shown in Fig. 3).
- Plot of selected waveforms (marked 3 in Fig. 3).
- Section for selection of element channels for observation (marked 4 in Fig. 3).
- Window for logs output (marked 5 in Fig. 3).
- Section for commands and plot navigation (marked 6 in Fig. 3).

There is a menu bar with three menus in the RM screen: *File* for save/restore operations, *RampCurve* for operations with ramp curves, *Tools* for different functions applied to ramps.

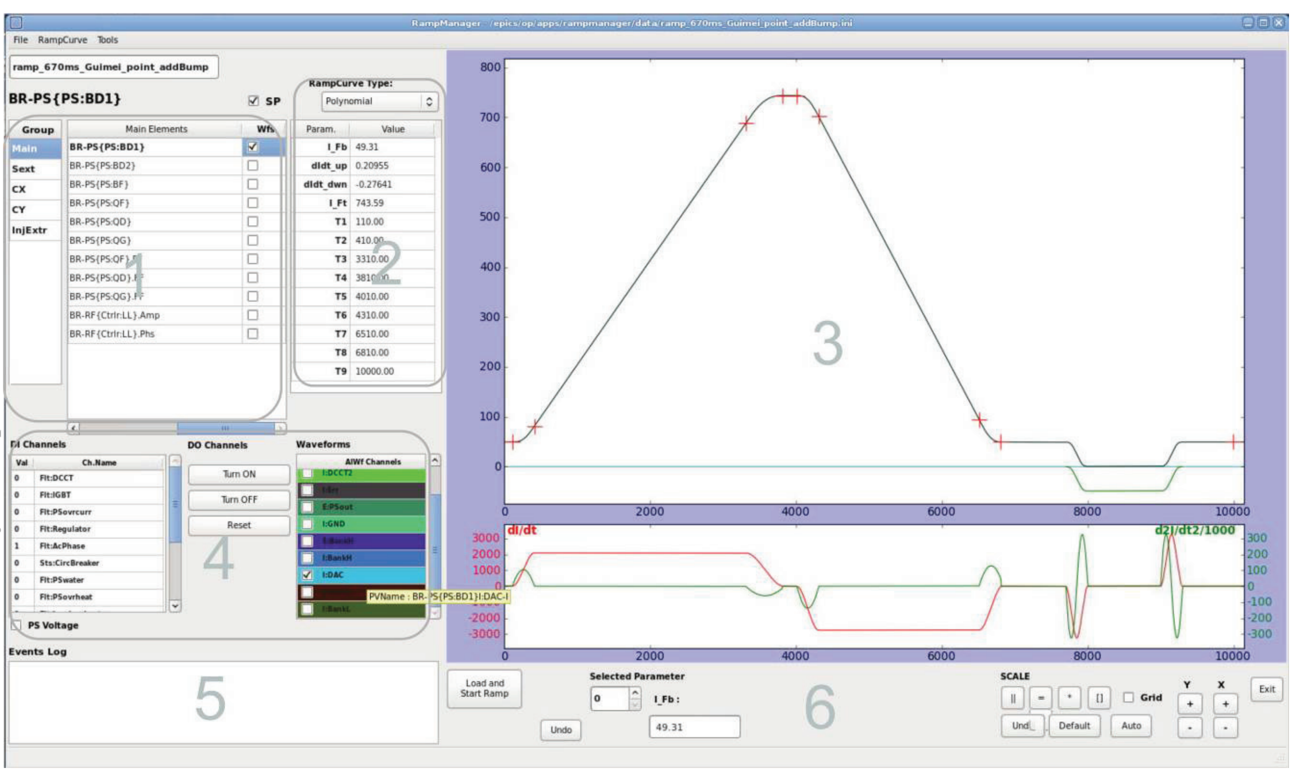

Figure 3: Ramp Manager main screen.

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Edition of the Ramp Waveform

RM has two modes of operation with the ramp curve: linear interpolation and polynomial approximation. The linear interpolation mode allows ramp edition in text format in the table and graphical edition in the plot with a help of mouse. The polynomial mode has the text mode of edition only.

There is a selector which provides switching between two modes of RM operation.

In the linear interpolation mode the table for text edition includes two columns: the first column is for time (number of a point in the 10k sequence), the second column is for signal value. In the polynomial mode the table includes polynomial coefficients for the ramp curve (see section 2 in Fig. 3).

If the signal derivative exceeds the limit RM marks with red this interval in the plot (see Fig. 4). This is an indication that the ramp curve can not be uploaded to PV.

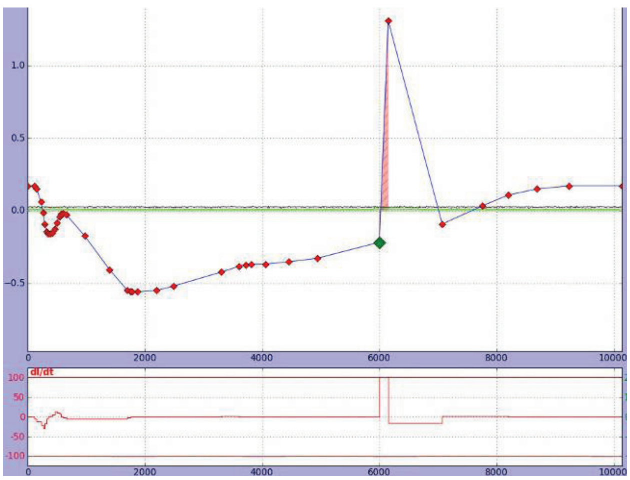

Figure 4: Ramping waveform for sextupole magnet with wrong setpoint.

The plot area is divided into two parts: the first part includes two setpoint signal and readback diagrams, the second part shows the first and the second derivatives.

RM automatically provides equality of the first point and the last point in the ramp waveform. When uploading to PV is triggered RM calculates all 10k points of the uploaded waveform and then performs *caput* procedure.

In polynomial mode the shape of the ramp is defined as a smoothed trapezoid (see section 3 in Fig. 3) with 4-degree polynomial for the main shape of the curve (see Eq. 1), and with 3-degree polynomials for small additional curves (bumps) for local correction of the main ramp (see Eq. 2 and Fig. 5).

$$\mathrm{I_M}(t)=\sum_{1}^{9}(a_i+b_i(t-t_i)+c_i(t-t_i)^3+d_i(t-t_i)^4)\Big|_{i-1}^{i} \qquad (1)$$

$$\mathrm{I_C}(t)=\sum_{1}^{4}(a_j+c_j(t-t_j)^3\Big|_{j-1}^{j} \qquad (2)$$

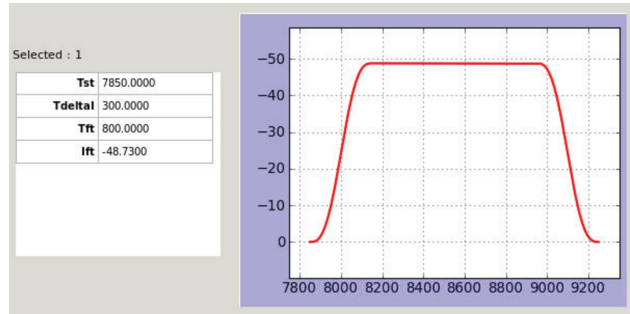

Figure 5: Correction bump.

All polynomials are defined with coefficients and time marks. Main ramp is divided into 9 intervals. The main curve is described with 9 time points and 4 values: two amplitudes and two derivatives (see section 2 in Fig. 3). The correction curve (bump) is described with 3 time values and one amplitude value (see section 3 in Fig. 3 and Fig. 5).

Common Operations with Ramp Curves

RM provides next operations with ramp curves available through *RampCurve* menu:

- *ReScale* – rescaling of the selected waveform; there are two methods of rescaling: absolute rescaling and relative rescaling from selected point.
- *Copy To* – the waveform copying to other selected elements applying a coefficient.
- *Save To* – the waveform saving to the selected or different file.
- *Load From* – the waveform loading from the file.
- *Import/Export From/To Text File* – operations for data transfer between different applications.

Special Tools

There are some features of the ramp handling which are implemented in RM through *Tools* menu:

- *SP Selector for Graph* – selector of element setpoints to plot them in the graph; any setpoint waveforms can be plotted with individual coefficient (see the example in Fig. 1).
- *Element Selector for Load* – selector of element setpoints to put them to PVs; all selected setpoint waveforms will be put sequentially to correspondent PVs; the result of each writing to PV will be printed in the log window of the screen (see section 5 in Fig. 3).
- *Extra Parameters* – editor of “extra parameters”; the control of some elements requires very specific behaviour of the ramp curve; this behaviour is described with additional parameters (see subsection “Specific control of pulsed elements” below).
- *Additional Channels View* – view of value of channels which are not read with the PSC.
- *Time Synchronization* – option to synchronize changing of time mark value for all main elements (dipoles and quadrupoles) in the polynomial mode of

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control; when the option is set ON a change of time mark for any element will result in the same change of corresponding mark for all main elements.

- *Bumps Editor* – launch the bump editor in the polynomial mode (see Fig. 4); the bump editor allows adding, deleting and switching ON/OFF bumps.

RF Control

There are two analogue control parameters for RF: amplitude and phase. Waveforms of 512 values are used in Low Level RF controller for the control, and these waveforms should be matched with 10k waveforms for other booster elements. Uploading of the waveforms to the controller require a performance of a sequence of operations: convert a new 10k waveform to 512 values, preparing a transition curve between previous and new waveform, uploading and performing transition waveform, then uploading and start performance of the new waveform. This sequence is implemented in RM as a continuous procedure with duration of about 10 sec. Results of all steps are typed sequentially in the log window of the RM screen.

Specific Control of Pulsed Elements

A double injection in 100 ms (stacking mode) is provided for the booster in order to increase a beam charge. Some injection pulsed magnetic elements should shot twice in 100 ms in the stacking operation mode. That requires a complete behaviour of control reference voltage for PSs before the second shot.

An example of the reference voltage for the injection septum and the tool for edition of additional parameters are shown in Fig. 6.

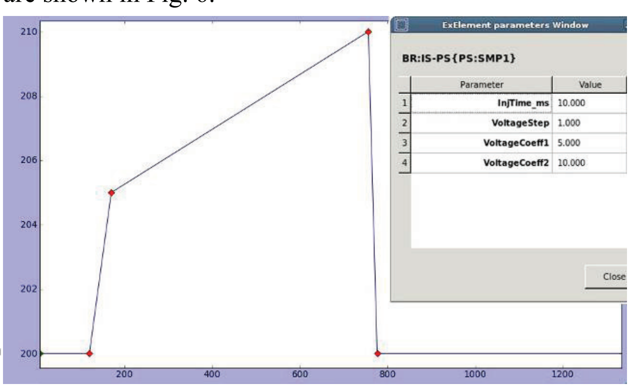

Figure 6: Reference voltage for the injection septum.

This is a flat with some exceed feedforward voltage for a charging device for acceleration of a charging process before the second shot. The level of the flat is set by an operator. A required accuracy and stability of the output pulsed current about 0.05% for both shots are achieved as a result of this approach application. The behaviour of the reference voltage is described with additional parameters specific for each element. Values of parameters are set in a special window (see Fig.6). Algorithms of correction for each element are implemented in the RM code.

Another example of specific control of injection kicker PS is shown in Fig.7. The values of the reference voltage are: 20 kV for PFN before the first shot, 13 kV before the second shot. This behaviour is described with a help of four parameters. The operator when adjust the beam injection normally sets two voltage levels for the first and second sots only.

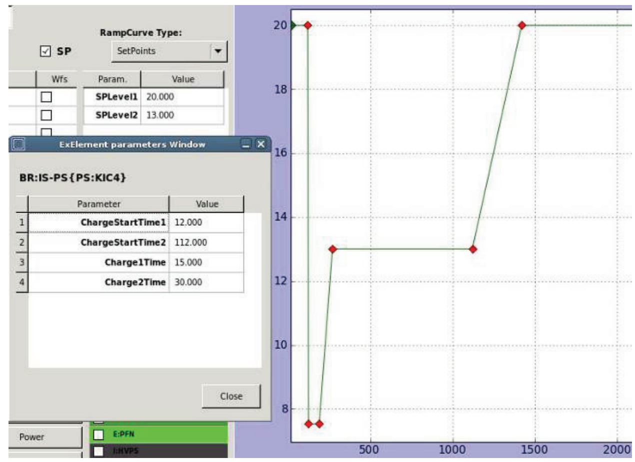

Figure 7: Reference voltage for the injection kicker.

CONCLUSION

Software solutions implemented for the booster controls provide a wide set of automatic and manual tools for handling of the ramp waveforms. Automatic functions implemented in IOC provide a correct uploading of setpoints to the front-end electronics and prevent damage of PSs. Operator tools implemented in Ramp Manager will be necessary for operator work at the booster commissioning and will be very useful at the next regular booster operation for provision of adjusting of the booster elements and for convenient manual control of the machine parameters.

REFERENCES

[1] S. Gurov et al., "Status of NSLS-II Booster," MOPEA053, Proceedings of IPAC'13; www.JACoW.org

[2] W. Louie et al., "Power Supply Control System of NSLS-II," WEB005, Proceedings of ICALEPCS'09; www.JACoW.org

[3] P. Cheblakov et al., "NSLS-II Booster Timing System," WEPMS015, Proceedings of ICALEPCS'11; www.JACoW.org

[4] P. Cheblakov et al., "Software for Power Supplies Control of the NSLS-II Booster Synchrotron," THPEA032, Proceedings of IPAC'13; www.JACoW.org

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