ENERGY RAMPING AT SIBERIA-2

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Abstract

Siberia-2 storage ring has great difference between injection energy 0.45 GeV and working energy 2.5 GeV. Beam lifetime at injection energy is equal to approximately 1 hour. In order to minimize beam losses of the stored beam it is necessary to accelerate energy ramping process. It is not very simple because power supplies of bending magnets, quadrupole lenses and sextupoles have different response time and behavior after changes in regulated current level. Magnetic elements are manufactured from non-laminated iron. It leads to slower field/gradient increasing at high current values.

Complicated algorithm with 9 intermediate regimes (collections of power supplies' settings) was developed to produce fast and efficient energy ramping. First, correction of closed orbit, betatron tunes and chromaticity is accomplished in each regime in static conditions. Special file is used to provide acceleration or deceleration of power supplies in dynamic conditions. This scheme allows to compensate betatron tune shifts during energy ramping. Power supplies are not stopped on intermediate regimes; speed of current changing is continuous function of time. This algorithm allowed decreasing ramping time down to 2 minutes 40 seconds. Beam losses are not exceeding 2 – 3%; betatron tune shifts as a rule are lower than 0.01. The algorithm can easily be modified to stop in any intermediate regime.

INTRODUCTION

Synchrotron radiation source SIBERIA-2 [1] has a big difference between injection energy (450 MeV) and working energy (2.5 GeV). Beam lifetime at energies below 1 GeV is small and does not exceed 1.5 hours. To avoid losses of electrons, immediately after the accumulation of the necessary current energy should be increased as soon as possible. The process of energy ramping consists in proportional change of magnetic field in bending magnets, field gradients in quadrupole and sextupole lenses. The difficulty lies in the fact that different magnetic elements have different curves of magnetization, that is, the dependence of the field/gradient on supply current. In addition, power supplies of the magnetic elements have different speed of reaction on change of nominal current. Magnetic elements are manufactured from nonlaminated iron, which leads to delay of the field in the working gaps of the magnets and lenses. As a result, betatron tuneshifts arise after the start of energy ramping. Too large shifts can lead to losses of the current on the closest resonances. Also chromaticity can change, resulting in additional losses due to a decrease of the dynamic aperture or the occurrence of instabilities in the beam.

To solve all these problems a unique algorithm for energy ramping was developed and implemented.

DIFFERENCIES IN MAGNETIZATION CURVES

Magnetic system of SIBERIA-2 includes one family of bending magnets, 6 families of quadrupole lenses, two families of sextupole lenses for chromaticity correction. The supply current of the bending magnets varies from 1270 A up to 7200 A, it determines the machine energy. The currents of the quadrupole power supplies vary from 80 A up to 760 A depending on the energy and number of the family, the currents of sextupole power supplies vary from 0.4 A up to 8 A. As a result saturation of iron exists at high energy, while residual magnetization manifests at low energies. The magnetization curve of the bending magnets is also influenced by busbar layout near current sensor. Thus, a simple proportional increase of the currents will lead to the betatron tuneshifts during energy ramping.

To facilitate the energy ramping process, 9 intermediate regimes were introduced at a distance of 10 - 20% in energy one from another. The regime means list of power supply settings. Magnetic measurements were conducted to determine right currents for all power supply families in each regime. Field in bending magnets was measured with an accuracy of 10^{-5} using NMR sensor. For the quadrupole lenses measurements were carried out by Hall effect sensor with an accuracy of 10^{-3}. Relative changes of the field gradients in each family in all intermediate regimes were measured. According to the results of measurements a correction of the setpoint currents was carried out so the relations of the gradients in different families in each regime remained the same as at the injection energy. Some of the results after this correction are shown in Fig. 1.

For more accurate reproduction of the results standard demagnetization cycle was introduced. After the work on the energy of 2.5 GeV currents of power supplies of the magnetic elements rise above the maximum working value, then gradually, over 80 seconds, fall below the minimum values of the injection energy, then regime of injection is restored. In every state a 30 seconds pause is maintained. The practice showed that after this demagnetization cycle betatron tunes returned to its initial values with a good accuracy of about 0.003.

TRANSIENT PROCESSES IN POWER SUPPLIES AND MAGNETIC ELEMENTS

Power supplies of the SIBERIA-2 magnetic elements have different speed of reaction to the change of current settings. In addition, magnets and lenses are manufactured

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from nonlaminated iron. This leads to the fact that the magnetic field/gradients in working gaps are installed with a time delay with respect to the change in the current. This is especially noticeable at high energies, where the influence of the saturation of iron is greater. In practice it turns out that the change of the field in the bending magnets lags behind the changes in the gradient of quadrupole lenses. This lag is well seen in measurement of betatron tunes during the energy ramping.

Betatron frequencies are measured through the beam excitation with a varying frequency and finding the resonant growth of the amplitude of transverse vibrations. This method has an accuracy of better 0.002, one measurement usually takes 1.2 - 1.4 seconds, which allows us to measure the frequencies during the energy ramping.

Under proportional rise of the currents in the bending magnets and lenses both betatron tunes begin to decrease, therefore field in magnets goes behind gradients in the lenses. Thus, for the effective energy ramping it is necessary to change current settings for bending magnets in advance with respect to the current settings for quadrupole lenses.

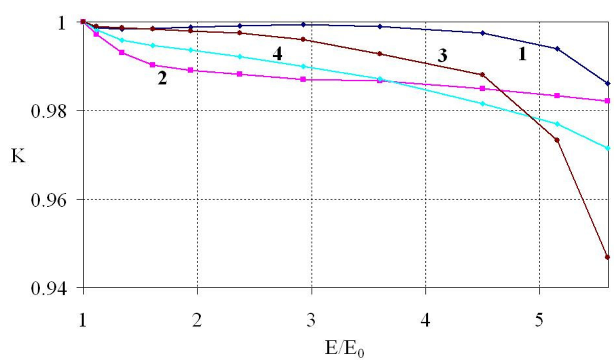

Figure 1: Magnetization curves $K = \left(\frac{H}{I}\right) / \left(\frac{H_0}{I_0}\right)$ for bending magnets (1), quadrupole family with minimum current (2), with maximum current (3), quadrupole with different yoke design (4). H – field or gradient, I – current of power supply, 0 index corresponds to injection energy. Curve (2) demonstrates the effect of residual magnetization (at the left), curve (3) shows the effect of the iron saturation (at the right). Points on the curves correspond to different regimes. Machine energy changes from E_0 = 450 MeV up to 2.5 GeV.

ENERGY RAMPING ALGORITHM

Adjustment of the energy ramping is carried out as follows:

- Adjustment of the intermediate regimes. Slow energy rising with 2 – 4 mA of electron current is carried out with a stop in each regime. Closed orbit correction, betatron frequency tuning, chromaticity correction are produced. Results are written to regime files, and then the cycle of demagnetization is performed.
- In the operating mode energy rising occurs without a stop at intermediate regimes. The algorithm is designed so that speed of current growth in the power supplies was a continuous function of time and changed linearly between neighboring regimes (Fig.3). The speed grows up to 1.6 GeV, after 2 GeV it begins to decline. At the beginning and at the end of the process the speed is equal to zero. So-called advance coefficients may be implemented into growth law. Additional change of the speed between the regimes is directly proportional to such coefficient and to a number of steps of the control program counted from previous regime.
- Several energy ramping are completed with the measurement of betatron tunes for the selection of the advance coefficients the number of control steps for each regime. Betatron tunes at the moment of regime passage must be equal to those seen at the injection energy. All values are saved in a file-descriptor of the ramping. The advance coefficients and the regimes duration are changed very rarely, only in case of significant modification of the algorithm (because of change of these parameters in one regime lead to the change of speed of current growth in rest part of the process).

  For operational adjustment of betatron tunes during the energy ramping the file-descriptor contains amendments to betatron frequencies for each regime and for possible changes in the frequencies within the regime. Correction of frequencies $\Delta Q_{x,z}$ is performed with the help of two quadrupole families F3 and D3, located in the region with zero dispersion function. regime. The same families are used for compensation of betatron tuneshifts $\Delta Q1_{x,z}$ in the middle of the regime installing. In this case, the correction of the current is concentrated within the current regime; the principle of continuity of the speed of current growth is still respected. Usually tunes amendments are modified once in 1-2 weeks (if it is necessary).
- When the last 2.5 GeV regime is installing the speed of current growth does not vary linearly with time, but like a square of time (Fig.2). This is done because one must compensate all the advance coefficients that were introduced previously. Power supply currents are strictly defined in this case and final speed for them must be equal to zero. So additional degree of freedom is needed in the law of the current changes.

Ramping file-descriptor looks as follows (Table 1). The table also contains four additional columns (not shown here): DQX,Z – amendments to betatron tunes for given regime, DQX1,Z1 – amendments in the middle of the regime recording. The process can be easily modified to stop in any intermediate regime. For this one need to delete rows from a table, following the required regime and increase the number of steps for the latter regime (for

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example, to stop at the regime 2G30 one needs to specify 220 steps instead of 90, at the 2G00 - 280 instead of 107). If the advance coefficient is equal to 100, it corresponds to additional 1% of speed V = dI/dt at the end of given regime installing. For bending magnets such coefficients' distribution provides the relative growth in the rate of current increase in the range of 1 - 2%, except for the last regime, on which the advance is compensated (see Fig. 2).

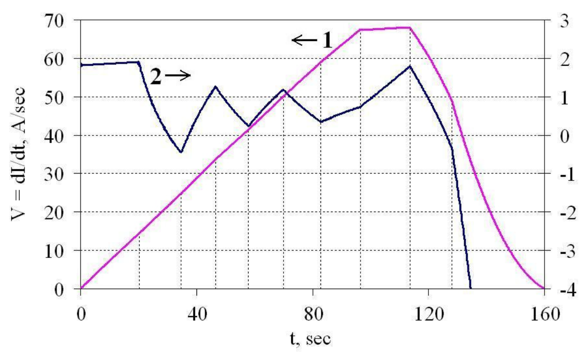

Figure 2: Speed of current growth in the power supply of the bending magnets (1) and relative increase of this speed due to advance coefficients (2). An influence of these coefficients is compensated in the last regime. Dotted lines correspond to regime borders.

Table 1: Typical view of the file-descriptor. NREG – regime's name, NSTE – number of steps for control program (160 msec each), KHS2, KD2 – advance coefficients for power supplies of bending magnets and D2 quadrupole family. Energy (in MeV) is given for reference.

NREG	NSTE	KHS2	KD2	Energy
G550	126	115	-70	499
G600	91	95	-70	598
G750	74	105	-70	719
G900	71	130	-70	868
1G00	75	160	-70	1060
1G30	81	190	-70	1307
1G60	85	210	-70	1608
2G00	107	340	-70	2012
2G30	90	520	-70	2305
2G50	200	0	0	2500

The view of energy growth and beam current changing are shown in Fig.3. Whole process takes 2 minutes 40 seconds, loss of current generally do not exceed 2 - 3%, they due to the low beam lifetime at energies below 1 GeV. Figure 4 demonstrates betatron tuneshifts around initial working point Q_x = 7.773, Q_z = 6.701 during energy ramping. Nearest resonances up to 5th order are presented. Resonances $2Q_x + 2Q_z = 29$ and $4Q_x = 31$ are the most dangerous, causing a loss of electrons. The greatest tune deviations occur when the last 2.5 GeV regime is installed.

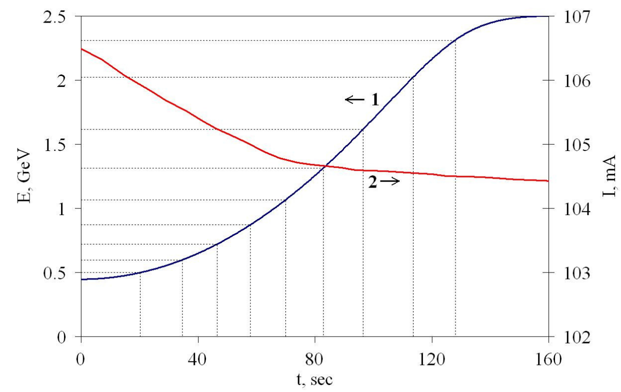

Figure 3: Energy growth (1) and electron current changing (2) during energy ramping (19/04/12). Dotted lines correspond to regime borders.

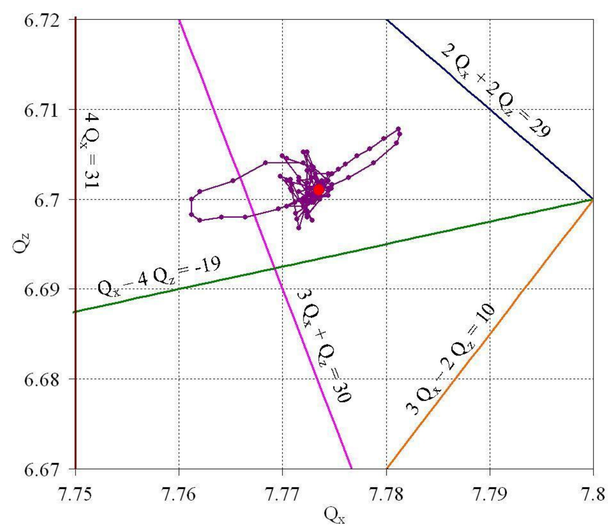

Figure 4: Betatron tuneshifts during energy ramping. Red point corresponds to initial (and final) working point. Nearest resonances up to 5th order are presented. Largest tuneshifts occurred in the last regime.

CONCLUSIONS

Fast and reliable energy ramping algorithm was developed and implemented at SIBERIA-2 storage ring. Whole process takes 2 minutes and 40 seconds, beam losses doesn't exceed 2 – 3 %, betatron tuneshifts are less than 0.015.

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