Upgrade of the 1.2 GeV STB ring for the SR utilization in Tohoku University

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Abstract. An electron accelerator complex, 300 MeV linac and 1.2 GeV booster synchrotron, had been routinely operated as a user facility at Tohoku University until the Great East Japan Earthquake damaged the accelerator seriously. In the last year some budget s were approved to partially reconstruct the accelerator. For the booster ring, some old power supplies of magnets are replaced. Furthermore some quadrupole magnets are also replaced to the combined function magnets of which sextupole component is included. Modifying the ring optics so as to introduce the horizontal dispersion into the position of combined magnet, this replacement will make it possible to correct the chromaticity. There has been no sextupole in the ring, so that the ring current is significantly limited due to head-tail instability. Hence this upgrade will bring the new capability into the ring as a synchrotron light source. Presently it is planned to utilize SR from the 1.3 T bending magnet for educational purpose in the field of SR application such as XAFS. The photon flux of 5.6E12 photons/s/mrad²/0.1%BW will be obtained around the peak energy region of 1 keV for this beam line in the case of 200 mA operation with the emittance of 160 nmrad. In addition to the beam line from bending magnet, a 2 m long straight section is also reserved for an insertion device for future application.

1. Introduction
A 300 MeV electron linac had been operated for 45 years at Tohoku University, which was constructed as the first machine for high energy experiment of nuclear physics at university in Japan. Since the linac was designed with old fashioned style and maintained without any radical upgrades, thus the performance such as emittance and peak current had declined so much in comparison with most recent machines. The linac was used for radioisotope (RI) production by irradiating targets with 300 Hz repetition rate, while performing another role as an injector for the 1.2 GeV booster synchrotron (STB ring) which was constructed in 1996 for nuclear physics experiments [1,2]. On a consideration of the recovery from the disaster, the Great East Japan Earthquake, it was decided to remove the high energy part of the damaged linac and construct new 90 MeV linac as a dedicated injector for the STB ring, while the low energy part of the old linac is going to be repaired for the RI production.

Regarding the STB ring, power supplies of pulsed magnets for beam injection are replaced as well as power supplies of the magnets working at the pattern operation with ramping time of about 1 second. Furthermore some quadrupole magnets located in the straight sections are also replaced to the combined function quads having sextupole component so as to correct the chromaticity with a modification of the ring optics which introduces the horizontal dispersion into the magnet location.
Since the STB ring was originally designed as an injector for a planned light source ring and also a pulse stretcher to generate the CW beam rather than a storage ring, thus the performance of the stored beam in the STB ring was not cared well. However, the STB had been operated with the booster-storage mode in these years to supply high energy gamma-rays, in which the high energy gamma-rays were produced via Bremsstrahlung using an internal target wire for a study of nuclear physics, and then stretcher operation had not been performed any longer. Hence it would be more valuable to consider an upgrade dedicated to booster-storage operation. It can be also expected to bring the new capability into the ring as a synchrotron light source by this upgrade work.

2. Lattice modification with combined magnet

The STB ring is consisted with 4-fold symmetry double-bend lattice. Since there was no space for any sextupole magnets to correct the chromaticity in the energy dispersive section, we have decided to replace the quadrupole magnets in the dispersion-free straight section to the combined magnets with sextupole. Therefore the finite value of the horizontal dispersion has to be introduced to the magnet position in the straight sections. This lattice modification is also meaningful for a user operation using high energy gamma-rays generated by internal target wire, because it helps to avoid a successive scattering with the holder of internal target for the scattered electrons [2].

Table 1 shows the parameters of the upgraded STB ring. The maximum energy will be increased more than 1.3 GeV to extend the gamma-rays energy to higher. Since the sextupole component is placed at the largest beta position, the sextupole strength of around 4.8 (8.4) 1/m³ for focusing (defocusing) magnet is not so much large, and thus it will be very efficient in correcting the chromaticity. As a result, it may secure larger dynamic aperture. Although a combined magnet is not possible to vary the sextupole strength relative to the quadrupole ones basically, some fine tuning of chromaticity can be accomplished by adjusting the dispersion function on the magnet position. Variation of chromaticity was estimated to be 0.8 for dispersion change of 0.1 m, which would be easily controlled. Using the average beta function of 7 m, Touschek lifetime was simply estimated to be longer than 48 hours, and thus the limiting factor to beam lifetime might be the scattering with the remnant gas in the vacuum chamber. Improvement of the vacuum system is surely significant issue in near future.

| Table 1. Parameters of the upgraded STB ring. |
|-----------------------------------------------|
| Circumference                                | 49.7 m                     |
| Maximum energy                               | > 1.3 GeV                  |
| Injection energy                             | 90 MeV                     |
| Betatron tune                                | (3.24, 1.18)               |
| Natural chromaticity                         | (-5.586, -4.427)           |
| Corrected chromaticity                       | (1.384, 1.232)             |
| RF frequency                                 | 500.14 MHz                 |
| RF voltage                                   | 400 kV                     |
| Natural emittance                            | 160 nmrad (@1.2 GeV)       |
| Momentum compaction                          | 0.0458                     |
| Dispersion at straight section                | 0.6 m                      |
| Beam current                                 | 200 mA (@1.2 GeV)          |
| Touschek lifetime                            | > 48 hours (@1.2 GeV)      |
2.1. Combined quadrupole magnet with sextupole component

New combined magnets have to be installed into the limited space by replacing the existing quadrupole magnets, so that those new magnets would have the same dimension with existing magnets except for their pole face shape. The ratio of field strength (S/Q) was designed to be 2.4 (3.8) for focusing (defocusing) magnet requiring the adequate dispersion function. The pole face shape is basically obtained by the equipotential surface for the given field strengths and a bore radius [3]. According to the 3D field calculation, however, it was found that the sextupole field had shorter effective length (~7%) than that of quadrupole, which yields smaller chromaticity of ~0.4. This discrepancy is rather too large to be ignored, and thus the actual pole face should be determined by taking this effect of shorter effective length into account. Regarding a saturation effect, although the sextupole component has much larger saturation than the quadrupole in higher current, it is expected to be marginal for the higher energy operation up to 1.3 GeV.

Dipole component seems to be another significant issue, which would generate the intolerable closed orbit distortion. Although no dipole component, in principle, might be exist in the mechanical center of magnet, practically finite truncation of equipotential surface to make the pole face will cause such dipole component in the center. In order to compensate the dipole component, we have considered shifting the magnet position at the moment. The results of field calculation show that the 0.8 and 2.0 mm offset are required to cancel it for the focus and defocus magnet. Clearance between the vacuum chamber and the magnet pole is very tight but acceptable for this position shift. To employ the back-leg coil can also be considered in order to cancel the dipole component, but will not be suitable because of the rather steep ramping time in a booster operation.

2.2. Beam injection and alignment tolerance

Efficiency of beam injection was estimated by tracking simulation, in which the bump magnets were assumed to have the flat top length covering seven turns for injected beam and slope decaying for the following three turns. Note the injection beam is an S-band macropulse with duration of ~1 µs. It was assumed that the continuous beam was injected into the RF buckets of the ring rather than a bunched beam, because the actual beam injection was not synchronized to the ring RF. The injected current for the first 20 turns are shown in figure 1, where the macropulse current of the injected beam was normalized to unity. Up to the fifth turn the injected current is linearly increased, however some beam loss would get occurred at the successive turns because of the hitting to the septum blade. The effect of misalignment is also shown in the figure, in which the uniformly distributed misalignment of ±100 µm in vertical direction is presented. According to the tracking simulation, the horizontal misalignment has much small effect comparing with the vertical direction.

![Figure 1.Injected beam current for the first 20 turns. Solid (dashed) line corresponds to the no error (±100 µm misalignment in vertical direction) case. Plots show the results of 100 sets of randomly misaligned magnets in vertical direction. Dashed line shows the average of such combinations.](image)
3. Expected performance of the light source

Figure 2 shows the expected performance of the upgraded ring. In the 1.2 GeV operation with 1 % coupling, the photon flux of 5.6E12 photons/s/mrad^2/0.1%BW would be obtained around the peak energy region of 1 keV for a bending magnet beam line, which may be not sufficient to be utilized in advanced research works but will be still useful for educational purpose in the field of SR application. Furthermore, as a future application, it is also expected to install an insertion device into the reserved space of a 2 m long straight section. If we consider a conventional undulator, which has the maximum K value of 2.0 and 36 periods with a period length of 50 mm, then the brilliance approaching 10^{16} photons/s/mrad^2/mm^2/0.1%BW will be realized in VUV region as shown in figure 2.

![Figure 2. Expected brilliance in 1.2 GeV operation with beam current of 200 mA and 1 % coupling. Solid (dashed) line corresponds to the radiation from undulator (bending magnet).](image)

4. Summary and future prospect

Recovery and reconstruction of the accelerator complex in Electron Light Science Center, Tohoku University, is now in progress vigorously. While the old linac is repaired for the users such as nuclear chemistry, the compact 90 MeV linac is newly constructed as the dedicated injector for the STB ring, thus this separation of the machine operation will make it much easier to arrange the user machine time. Furthermore, it will drastically improve the tuning work required in every start-up of machine tuning, which will greatly pull up the facility’s activity, because the low energy part of the old linac had much different setting of parameters depending on the user requirements and also had very poor reproducibility so far. Regarding the upgrade of the STB ring towards the SR utilization, the stored beam current will be increased by replacements of power supplies and magnets. Although there are still some issues to be improved such as the vacuum system, it is expected to open the door to much wider application rather than the nuclear physics in near future.

References

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