STATUS OF THE 1.3 GeV BOOSTER SYNCHROTRON FOR GENERATING HIGH ENERGY GAMMA RAYS AT TOHOKU UNIVERSITY

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Abstract

The 1.3 GeV booster synchrotron (BST ring) has been utilized to supply high energy gamma rays for nuclear physics experiments at Research Center for Electron Photon Science, Tohoku University. The photons with around one GeV are produced via bremsstrahlung by an internal target wire. To realize higher duty in the gamma ray generation, it is required that a ramping time for beam acceleration should be short. Thus a dynamical control for steering magnet was introduced to supress COD due to eddy current in a chamber wall. Present operational status and recent progress of beam performance in the BST ring are reported.

INTRODUCTION

Upgrade of accelerator complex was carried out with recovery work for the Great East Japan Earthquake in March 2011 at Research Center of Electron Photon Science, Tohoku University [1, 2]. The restoration of user machine time was accomplished in 2013 and since then the approved beam time has been regularly implemented as scheduled.

In a typical operation of the 1.3 GeV BST ring, electron beam injected from a 90 MeV linac is immediately accelerated to the top energy and then an internal target wire is inserted to orbit of the stored beam to generate high energy gamma rays via bremsstrahlung. Duty factor for the gamma ray generation is about 60 ~ 70 % depending on the required gamma rays intensity. Since the radiation damping time is too much long for injection energy of 90 MeV, beam stacking is not applied for beam injection. However stored current more than 30 mA can be obtained at the top energy by only one macropulse beam from the linac, which is sufficient amount for present application. There are eight dipole magnets in the ring, and each dipole magnet has a pole width of 250 mm and gap of 50 mm. There are two beam lines for GeV gamma rays at dipole magnets, BM4 and BM5. Momentum of the scattered electron is measured by the tagging detectors installed inside these dipole magnets to tag the gamma ray's energy.

In order to supply gamma rays efficiently, ramping time from 90 MeV to 1.3 GeV is preferred as short as possible. On the other hand, steep ramping slope results in the large eddy current in a vacuum chamber wall, so that a compromise should be made with respect to the ramping slope. One specific situation in BST ring is to have the special vacuum chambers at BM4 and BM5, which have wider horizontal shape to extract the gamma rays and also additional flange for thin titanium window to detect the

scattered electrons at the tagging counter. Therefore these chambers make kick sources through the different contribution of the eddy current from the other six chambers in the ring.

EDDY CURRENTS IN A VACUUM CHAMBER WALL

Under the time-varying dipole field, eddy currents in a vacuum chamber generate magnetic field. The multipole expansion of the total magnetic field due to the eddy currents is given by

$$B_e(z) = \sum_{n=0}^{\infty} C_n z^n \int_{V.C.} x(\alpha_n + \beta_n) ds , \qquad (1)$$

where the coordinate is represented as complex $z = x + iy$ and integral is taken over the vacuum chamber wall [3]. In Eq. (1), C_n, α_n and β_n are given by

$$C_n = \frac{\mu_0 \sigma}{2\pi n!} \frac{\dot{B}}{B_0} \left(\frac{\pi}{2g}\right)^{n+1} , \qquad (2)$$

and

$$\alpha_n = \left. \frac{\partial^n \tanh\left(z - \frac{\pi z_c^*}{2g}\right)}{\partial z^n} \right|_{z=0} , \qquad (3)$$

$$\beta_n = \left. \frac{\partial^n \cosh\left(z - \frac{\pi z_c}{2g}\right)}{\partial z^n} \right|_{z=0} , \qquad (4)$$

where σ is the electrical conductivity, $\dot{B}$ is the rate of change of the field, B_0 is the main dipole field, g is the gap between iron plates of dipole magnet and z_c is the complex coordinate of a current filament in the chamber wall. In the following estimation, we assumed a rectangular vacuum chamber with a symmetric configuration in the vertical direction, which is made by stainless steel with the conductivity of 1.28E6 1/Ω-m. The chamber wall thickness is 3 and 6 mm for top/bottom and side plates, respectively. The full width of normal and BM5 chamber are 132 mm and 191 mm respectively, while the half height is 23 mm for both chambers. In the current operation of BST ring, typical ramping slope is about 0.7 T/s, which seems to be not so fast, however it results in still large COD to lose the significant amount of the beam current during the ramping.

The relative field error is calculated for the wider and asymmetric rectangular chamber BM5 as well as the normal chamber as shown in Figs. 1. In the calculation,

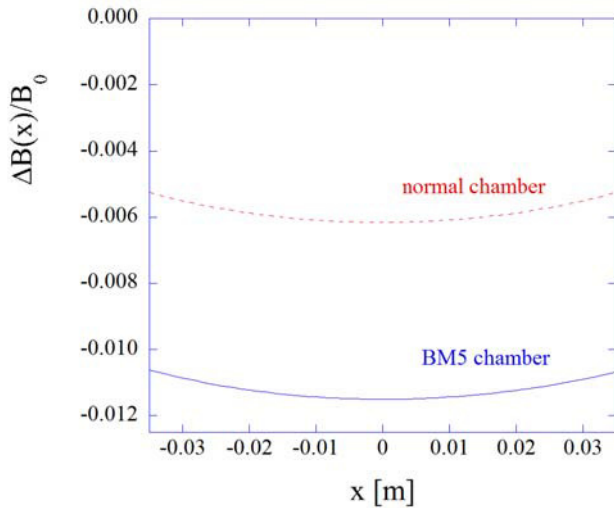multipoles up to n = 8 are taken, but dominant contributions are dipole and sextupole components.

Figure 1: Field reduction due to the eddy current as a function of the horizontal position. Multipoles up to n = 8 are taken into account.

It is found that the wider chamber for BM5 has almost two times larger field reduction in the central region than that for the normal chamber. This field difference corresponds to an additional kick angle of 4 mrad, which generate large horizontal COD more than 20 mm in peak-to-peak. The chamber was assumed to be simple rectangular shape with asymmetric arrangement with respect to the horizontal mid-plane, but actual chamber has rather complicated shape and structure, so that this result might be not so much accurate for the field error.
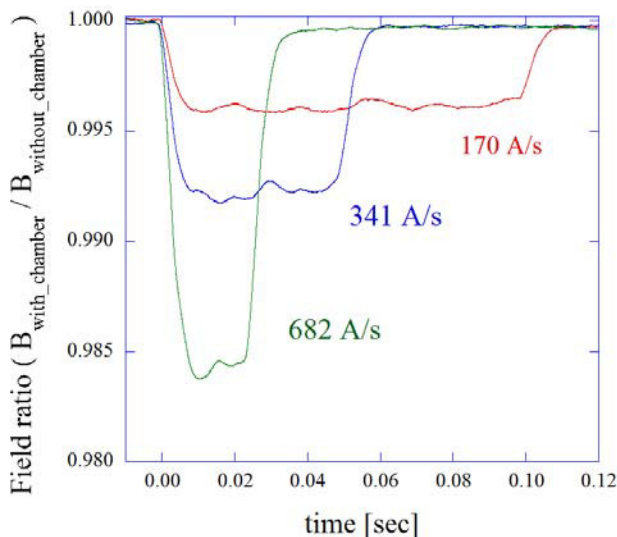

Figure 2: Measured field ratios in the dipole magnet for ramping slope dI/dt = 170, 341 and 682 A/s. Field measurement was carried out with a Hall probe.

Concerning the dipole magnet BM5, we measured a time-dependent magnetic field strength in case with and without the vacuum chamber inside the pole gap of the magnet to investigate the effect of eddy current in the vacuum chamber. BM5 is mounted on the rail and moved to inside the ring by 40 cm so as to install the tagging detector inside the magnet yoke, thus we can measure the magnetic field without vacuum chamber and the field ratios ($B_{\text{with\_chamber}}/B_{\text{without\_chamber}}$) are obtained for some ramping slopes. As one can be seen in Fig. 2, the field ratio is almost linearly dependent on the ramping slope. The ramping slope in typical operating condition is 590 A/s and the corresponding field reduction is deduced to be 1.38 %, which is mostly consistent with the estimated value in Fig. 1.

DYNAMICAL CONTROL OF STEERING MAGNET

In order to suppress dynamical COD change in ramping process, it is required to control output current for steering magnet dynamically. Power supply for the steering magnets originally used in BST ring is equipped with a pattern memory and can be operated with a sequence mode that controls the output current as synchronizing with the ramping pattern. However time response for the output current in this mode is quite slow and limited only to 50 ms. Recently we have introduced a dynamical control mode for the steering magnet by applying an analog signal to the power supplies. In this system, power supplies are operated as amplifiers (namely power booster mode) and much faster time response can be realized. Figure 3 shows a configuration of control system for the steering magnet. Analog output module consists of FPGA and DAC, which are installed in CompactRIO (National Instruments Co.). A specified pattern data is converted to sequential data and stored in FPGA (Spartan-6 LX45). The stored data, then, are transferred to DAC (NI9263, ±10 V, 16 bit) with each 20 μs clock timing and converted to analog data synchronized with an external trigger. The originally used power supply (KIKUSUI PBX20-5) for steering magnet has also power booster mode as well as the sequence mode that can be adopted to our new system, thus whole system was tested under the actual condition.
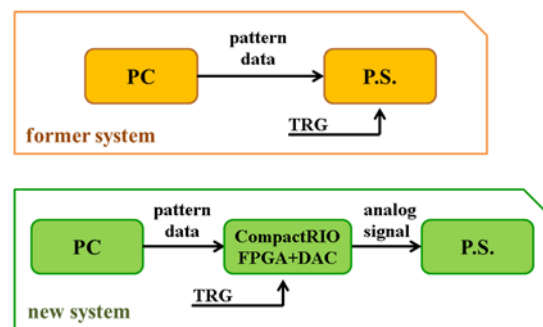

Figure 3: Configuration of former and new control system for steering magnet.

Prior to the beam operation, we confirmed the improvement of the response time of output current. The power supply was tested under a set value with the much steeper slope of 1 A/ms than nominal value in specification sheet. Figure 4 shows the comparison of the time response of output current for the former and new control system, in which it is found that the delay time from the trigger signal is drastically improved. Furthermore the ramping slope is also improved and almost approaching to a limit of 50 A/s defined by power supply and coil impedance. As the result of this upgrade, the tracking capability for ramping pattern was much improved and thus beam loss in the acceleration period has been also reduced.
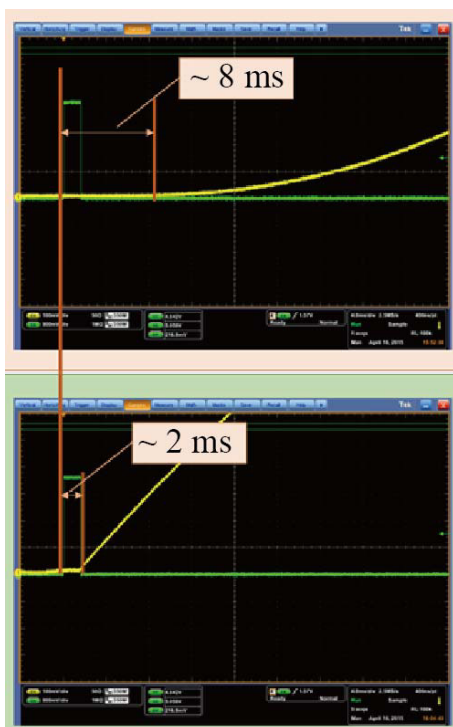

Figure 4: Comparison of output response for former (upper) and new (lower) control system. (Scales: 100 mA/div, 4 ms/div)

SUMMARY AND FUTURE PROSPECT

In order to suppress the COD change in ramping process due to eddy current in the vacuum chamber wall, the dynamical control for the steering magnet was introduced by employing the power booster operation with CompactRIO system. Combining with effort of realignment work for the whole ring, this improved the injection-acceleration efficiency to over 50 %, and the beam current more than 30 mA are obtained at the top energy by only one macropulse injection with peak current of 40 mA.

The ramping slope of ~600 A/s for dipole magnets in the current operation is still 60 % for the maximum slope defined by power source, so that it should be possible to increase the slope to improve the duty factor for the pattern operation. However there is still a problem in power

supply for steering magnet which prevents the increase in ramping slope. Figure 5 shows a beam orbit response for a steering magnet with various slopes of the output current in the 1.3 GeV operation. It was found that this power supply has a ringing behaviour for the larger slope of about 10 A/s and which is actually wiggling the beam. Concerning this issue, very recently we have been trying to replace these to more stable power supplies, and found that, at least, model BWS60-5 (Takasago Ltd.) is available for the slope more than 100 A/s without the ringing response. Now we are preparing to replace all power supplies to this model, and then optimization of the orbit control in the ramping process will be performed to improve the duty factor and also further reduce the beam loss.
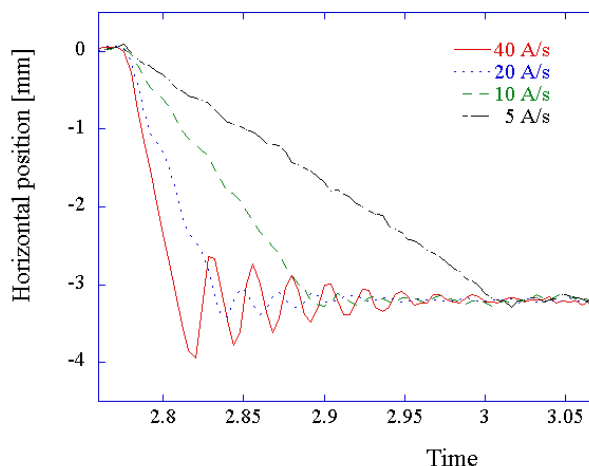

Figure 5: Example of a beam orbit response for a steering magnet at the 1.3 GeV operation.

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