STATUS OF UPGRADE PROJECT OF THE 1.2 GEV BOOSTER SYNCHROTRON AT TOHOKU UNIVERSITY

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Abstract

A 1.2 GeV electron booster synchrotron has been operated for nuclear physics experiment since 1997 at Electron Light Science Centre, Tohoku University, in which the high energy gamma-rays via Bremsstrahlung has been supplied for hadron physics. After the Great East Japan Earthquake in March 2011, recovery and reconstruction work of the accelerator complex is in progress. While a compact 90 MeV linac is newly constructed as a dedicated injector for the booster, old power supplies for synchrotron magnets and also pulsed magnets for beam injection are replaced. Furthermore some quadrupole magnets are replaced to the combined function ones containing sextupole component to correct the chromaticity. The power supplies and the combined magnets had been manufactured and those installations were completed. Current status of the booster upgrade is presented.

OVERVIEW OF UPGRADE PROJECT

A 300 MeV electron linac had been operated at Tohoku University since 1967. A low-energy part of the linac was used for radioisotope (RI) production by irradiating targets with 300 Hz repetition rate, while the whole linac was mainly operated as an injector for the 1.2 GeV booster synchrotron since 1997. Concerning the recovery from the great earthquake, the high energy part of the damaged linac had been removed and then a 90 MeV injector linac was newly constructed [1]. Meanwhile the low energy part of the old linac was repaired for the RI production. Regarding the 1.2 GeV booster, some quadrupole magnets in the straight sections were replaced to the combined function quadrupole magnets having sextupole component. Modifying the ring optics to introduce the horizontal dispersion on the combined magnet position, this replacement work makes it possible to correct the chromaticity [2]. Four power supplies for dipole and three quadrupole families capable of pattern operation with ramping time of about 1 second have already been installed, which have excellent performance of good stability and small tracking error over very wide energy range from 90 to 1300 MeV. Power supplies of pulsed magnets for beam injection were also newly replaced as well as the control system of those devices, and thus more reliable and stable beam operation can be expected by these replacement works.

COMBINED FUNCTION MAGNETS

Focus (QSF) and defocus (QSD) combined function magnets were newly fabricated, which should have essentially the same dimensions as the old magnets except the pole face shapes. Although the pole face shape of a combined function magnet can be basically deduced from an equipotential surface for a given field strengths and a bore radius, a 3D field calculation shows that the sextupole field has shorter effective length (~7 %) than that of the quadrupole. Therefore the actual pole face was determined by taking this effect of shorter effective length into account. The ratio, mL_S/kL_Q, of the integrated field strength for sextupole component to quadrupole was designed to be 1.2 (1.9) for QSF (QSD) magnet requiring the adequate dispersion function at the straight section to correct the chromaticity, where the both components mL_S and kL_Q are expressed as $B_yL(x) = kL_Q \times x + mL_S \times x^2$ with the vertical field in the median plane. Manufacture and field measurement of the magnets were carried out by SIGMAPHI. Fig. 1 shows the result of the field measurement employing the rotating coil [3].

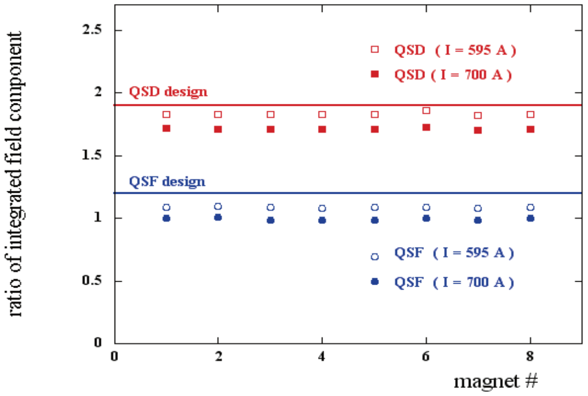

Figure 1: Result of field measurement of combined function magnets. Circle and square plots show the ratios of the integrated field strengths for eight QSF and QSD magnets, respectively.

For the both of QSF and QSD magnets, though it was found that the integrated quadrupole components are in good agreement with the field calculation by TOSCA but sextupole components are smaller than the calculation. As a result, the ratio mL_S/kL_Q became smaller than designed one. We have anticipated that this discrepancy would be still acceptable because of possible variation of the dispersion function for the chromaticity correction.

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Since the sextupole component has much stronger saturation than the quadrupole, the field ratios for the maximum excitation current are, however, getting smaller comparing with the nominal current, which must be also taken into account for the actual beam operation.

POWER SUPPLIES FOR DIPOLES AND QUADRUPOLE MAGNETS

Power supplies for the dipole and three quadrupole families (QSF, QSD and QC) were manufactured by Toshiba Mitsubishi-Electric Industrial Systems Corporation (TMEiC), which were originally developed for a medical heavy-ion facility [4]. These are high-precision IGBT chopper type power supplies that have very excellent performance of a current ripple less than $\pm1\times10^{-5}$ and also a tracking error less than $\pm1\times10^{-4}$. Main parameters of the power supplies are listed in Table 1. The maximum output currents have been increased to extend the beam energy up to 1.3 GeV. A PXI system communicates with a built-in memory module in the each power supply via Ethernet to send 16 bit pattern data, while timing signals such as clock and trigger are transferred via RS422.

Table 1: Main parameters of power supplies

	Dipole	QC	QSF, QSD
Min. current	80 A	40 A	35 A
Max. current	1400 A	800 A	700 A
Output voltage	645 V	55 V	77 V
Ramping rate	980 A/sec	665 A/sec	565 A/sec

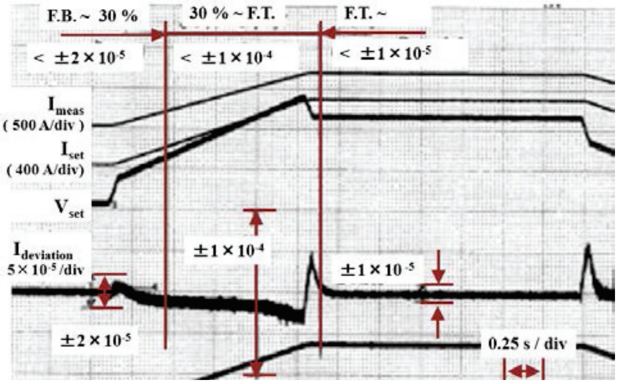

Figure 2: Example of the pattern operation with the actual QSF magnets. Deviation ($I_{deviation}$) of the measured current (I_{meas}) from the reference value to be set (I_{set}) is quite small in a very wide range.

Figure 2 shows an example of the pattern operation. Tracking errors are within $\pm1\times10^{-4}$ and stability at flat-top is less than $\pm1\times10^{-5}$, which satisfy specifications well. It is worth noting that the ramping pattern in the figure is not tuned well, thus the pattern optimization will allow further to reduce the tracking error.

POWER SUPPLIES FOR PULSED MAGNETS

Pulsed power supplies for both a septum and kicker (bump) magnet for beam injection were manufactured by Nissin Pulse Electronics Co. Ltd. The power supply for the septum magnet, which is driven by half sinusoidal pulse, consists of 200μF/800V main capacitor, 600V/1.3A charging power supply, thyristor stack FTS1000HJ and control units, etc. The kicker magnet power supply is composed of a charging power supply HDV-15K10ST to drive PFN, thyratron CX1191D and other control units. Measured waveform of the output current for the kicker magnet is shown in Fig. 3, where well suppressed ringing tail can be seen. The maximum output current of kicker magnet was set to 220 A taking some margin for future upgrade of injection energy up to ~150 MeV. The other parameters are listed in Table 2 including the power supply for the septum magnet.

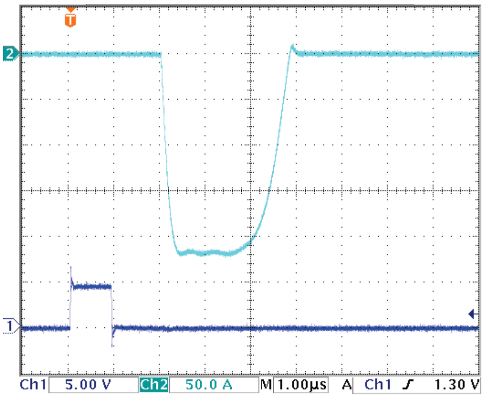

Figure 3: Measured waveform of output pulse for the kicker magnet at the maximum current of 220 A.

Table 2: Main parameters of pulsed power supplies

	Kicker magnet	Septum magnet
Max. current	220 A	1210 A
Pulse width	> 1 μs @flat part	200 ± 10 μs
Current stability	< 1 % (p-p)	< 2 % (p-p)
Fall time	< ~0.5 μs	-
Timing jitter	< 10 ns	< 10 ns
Rep. rate	> 10 pps	> 10 pps

RE-ALIGNMENT OF MAGNETS

Re-alignment work of all dipole and quadrupole magnets was performed by SIGMAPHI employing a laser tracker, Leica AT401. Fig. 4 shows a partial view of the booster synchrotron. Since many locations inside the booster ring are occupied by many objects; tall cabinets, a large klystron and steps of over-bridge, which block sight from some places, thus the tracker was located at very high position (> 2.7 m), well above the top of the cabinets to allow direct view of the top of the magnets, as seen in Fig. 4. Nevertheless the tracker was required to be mounted on three different locations because the direct sight was still prevented for some magnets. Since the original coordinate system had been lost and no accurate reference position was available for the re-alignment, therefore new coordinate system was tentatively defined using dipole magnets themselves as the first step, which was obtained so as to minimize the displacements from the original locations for all dipole magnets. After the rough alignment based on the tentative coordinate system, more precise coordinate system for the re-alignment was redefined again in the same manner.

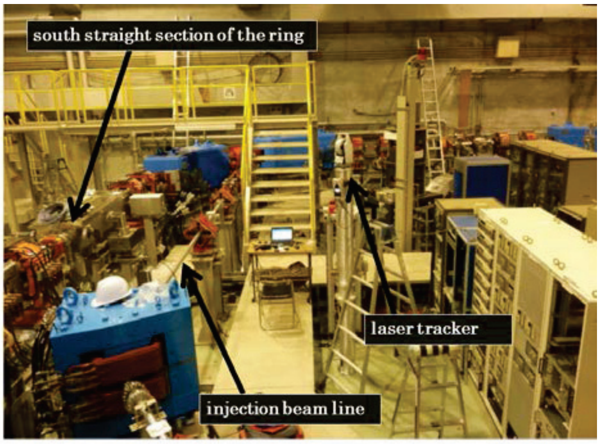

Figure 4: Partial view of the booster synchrotron. The laser tracker is located at very high position inside the booster ring.

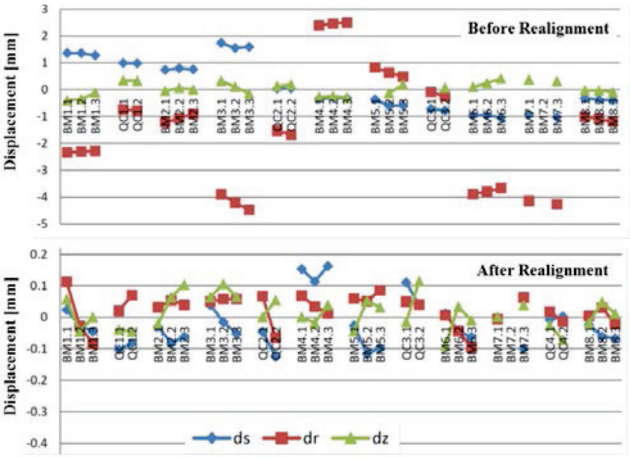

Figure 5: Result of reference position measurements before and after the re-alignment of all dipole and QC magnets. Note that the vertical axis is ten times magnified in the lower graph.

Fig. 5 shows the measured displacements for dipoles and QC magnets before and after the re-alignment based on the new coordinate system further redefined, where the coordinate *s* denotes the position along the central orbit, *r* perpendicular horizontally to the central orbit and *z* the vertical direction, respectively. One peculiar feature concerning the alignment of the combined function magnet might be an offset issue of the magnetic center with respect to the mechanical one. In order to eliminate the dipole component on the beam axis, we decided to shift the magnet position itself. According to the field measurement result, the required horizontal offset to cancel the dipole component is about 0.8 and 1.5 mm for QSF and QSD, respectively. In addition, the field measurement also revealed that the rotation with the order of 1 mrad around the beam axis also has to be corrected. Consequently this horizontal-vertical coupling with offset shift made the re-alignment work really complicated and required much time to carry out the magnet positioning in horizontal and vertical directions simultaneously. After the tremendous effort for this re-alignment work, finally all the magnets were well aligned within the tentative tolerance of ±0.2 mm. Further fine alignment will be performed with beam-based method.

SUMMARY

The progress in recovery and upgrade project of the booster synchrotron is being made at Tohoku University. Key components such as combined magnets and power supplies had been already installed, and many cabling works and development of new control software are still underway. Beam tuning in the new injector linac has been already started, and then beam commissioning of the booster synchrotron will be started soon.

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REFERENCES

[1] S. Kashiwagi, et al., “Construction of a New 90 MeV Injector Linac for the 1.2 GeV Booster Synchrotron at Tohoku University”, TUPME018, these proceedings.

[2] F. Hinode, et al., “Upgrade of the 1.2 GeV STB Ring for the SR Utilization in Tohoku University”, J. Phys.: Conf. Ser. 425, (2013), 072011.

[3] L. Bottura, “Standard analysis Procedures for field quality measurement of the LHC magnets, Part I: Harmonics”, LHC-M-ES-0007 rev 1.0 (2001).

[4] C. Yamazaki et al., “Development of a Power Supply for the Bending Electromagnets of the Heavy-Ion Facility at Gunma University”, Proceedings of the 7th Annual Meeting of Particle Accelerator Society of Japan, (2010), pp590-592, (in Japanese)