LATTICE MODIFICATION OF A 1.2 GEV STB RING FOR GENERATION OF HIGH ENERGY GAMMA-RAYS USING INTERNAL TARGET WIRE

F. Hinode*, H. Hama, M. Kawai, A. Kurihara, A. Miyamoto#, M. Mutoh, M. Nanao, Y. Shibasaki, K. Shinto†, S. Takahashi, T. Tanaka, LNS Tohoku University, Sendai 982-0826, Japan

Abstract

A 1.2 GeV Stretcher-Booster Ring (STB ring) has been routinely operated at Laboratory of Nuclear Science (LNS), Tohoku University. The STB ring has functions of a pulse-beam stretcher and a booster-storage ring [1, 2]. In the booster-storage operation, high energy gamma-ray beam generated via bremsstrahlung from internal target wire is utilized for experiments of nuclear physics. Some fractions of circulating electrons are also deflected in the target wire due to Coulomb scattering without significant loss of the energy. The scattered electrons that are not getting out of the dynamic aperture once can circulate in the ring. Such electrons, however, would hit the chamber walls and supports of the target wire during further turns, because they have very large betatron amplitude. Consequently the Coulomb scattered electrons must be a source of significant background and may cause a degradation of gamma-ray beam quality. The quality of the gamma-ray beam has been improved by modifying the lattice functions of the ring. We present the details of the modification and the result of the improvement.

GAMMA-RAY GENERATION VIA BREMSSTRAHLUNG FROM INTERNAL TARGET WIRE

In these years, the STB has been mainly operated with the booster-storage mode for the experiments of nuclear physics. Table 1 shows main parameters of the STB ring. In the end of FY2002, new experimental hall was constructed, so that one more gamma-ray beam line was able to be utilized. For this new beam line (BM5), high energy gamma-ray beam is generated via bremsstrahlung from a radiator (internal target wire) which is inserted onto the electron beam orbit at just upstream of a bending magnet as shown in Fig. 1. A tagger detector is placed inside the bending magnet, and measures an electron momentum which emitted bremsstrahlung by utilizing the bending magnetic field. Carbon fibre of diameter of 10 μm is used as the target wire, and which is fixed by a wire fork made by aluminium alloy. The inner heights of wire fork and typical vacuum duct are 22 and 40mm, respectively (see Fig. 2). The gamma-rays are irradiated onto a target in the experimental hall placed in 17m downstream from the radiator.

In the first stage of beam commissioning for the new gamma-ray beam line, there were serious problems; 1) very poor tagging efficiency (~20%) for tagged gamma-rays, 2) abnormal spread of gamma-ray profile in vertical direction. These phenomena have not been observed in another gamma-ray beam line (BM4). After the investigation about these phenomena, it was found that Coulomb scattered electrons hit the wire fork, so that it caused abnormal spread of gamma-ray profile in vertical direction. Furthermore the tagger detector counts a lot of background caused by the scattered electrons, which considerably decreased the tagging efficiency.

Table 1: Parameters and status of the STB ring.

Lattice type	Chasman-Green
Superperiodicity	4
Circumference	49.7 m
Maximum energy	1.2 GeV
Injection energy	0.2 GeV (nominal)
Betatron tune	(3.22, 1.15) *
Chromaticity	(~ -5.5, ~ -4.7)*
RF frequency	500.14 MHz
RF voltage	140 kV
Harmonics	83
Natural emittance	170 nmrad (@ 1.2 GeV)
Momentum compaction α	0.0378
Dispersion	< 10 cm*
x-y coupling coefficient	0.005*
Beam current	< 20 mA* (@ 1.2 GeV)
Lifetime	~ 10 min* (@ 1.2 GeV)

* Measured value

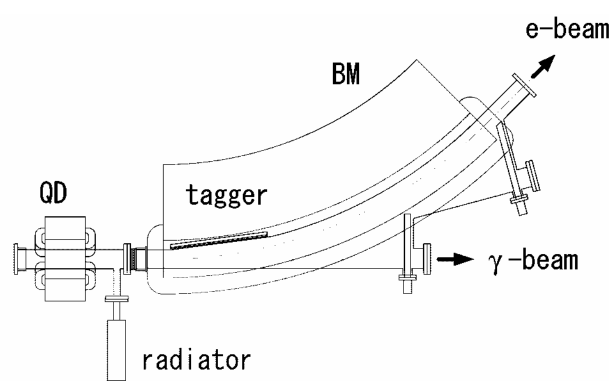

Figure 1: Layout of a new gamma-ray port (BM5).

A tracking simulation was done in order to clarify this situation. In the simulation, below conditions are applied; 1) circulating electrons are scattered by the wire target with angle of 0 to 3 mrad which is less than critical angle, 2) effect of energy loss of 0.45 to 3.5 % are included. The second condition expresses that electrons can circulate over several turns, but they exist in the out of rf bucket

* hinode@lns.tohoku.ac.jp
# Present address: Hiroshima Synchrotron Radiation Center, Hiroshima University, Higashi-Hiroshima 739-0046, Japan
† Present address: Department of Quantum Science and Energy Engineering, Tohoku University, Sendai 980-8579, Japan

and is going to be lost after all. The tracking calculation is continued up to 20 turns. Under these conditions, the electron positions at the wire target location are simulated. Fig. 2 shows the result of the electron beam profiles before and after scattering. The vertical beta function has almost the maximum value at the wire target, so that the scattered electron beam spread over a larger space than the wire fork's height. Furthermore, there is no dispersion at the location. Therefore the electrons which had lost their energy slightly can go back to the central orbit again. This makes the problem more serious. Fig. 3 shows the beam loss rate for the scattering angle. It was found that the scattered electron was drastically lost for the scattering angle larger than 1mrad and could never circulate for the angle larger than 7mrad.

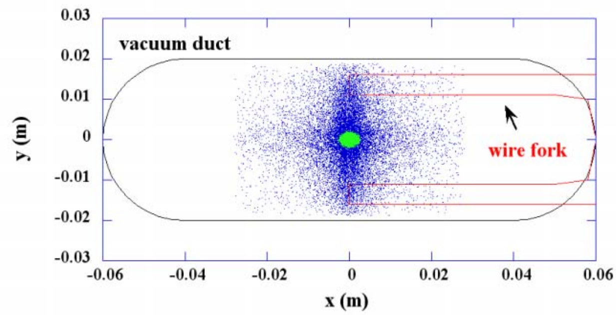

Figure 2: Electron beam profiles before and after scattering (simulation).

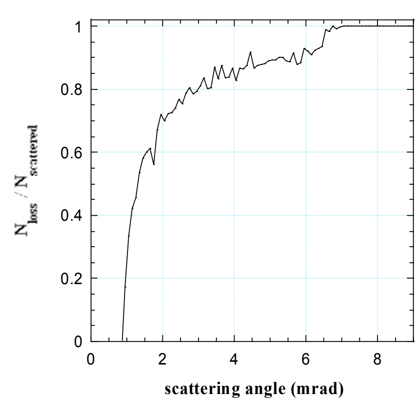

Figure 3: Beam loss rate for the scattering angle.

LATTICE MODIFICATION AND IMPROVEMENT OF GAMMA-RAY BEAM QUALITY

It is considered that if the vertical beta function at the wire target is set to lower value, the number of electrons which hit the wire fork can decrease, and thus the background to the tagger detector can reduce. Furthermore, if the sufficiently large dispersion in horizontal is introduced at the wire position, we can prevent the off-energy electrons going back to the wire region. Consequently, it is expected that the quality of gamma-ray beam can be improved by these modifications.

Based on the above consideration, the beam optics was modified in the STB ring. According to the tracking simulation, the distribution of scattered electrons spread over the full space in a vacuum duct with an aperture of 40mm. The vertical beta function at the wire location, therefore, must be reduced to 10m which is the half of present value in order to avoid the situation that the scattered electrons hit the wire fork. Also, the introduced dispersion larger than 50cm was aimed at. To fulfil these requirements, there is no choice but to construct the beam optics which destroys the symmetry in lattice. Fig. 4 shows the modified lattice functions which has a two-fold symmetry, in where the operating point is (νx, νy) = (3.234, 1.085). To achieve lower vertical beta function at the radiator location, it can not be avoided that vertical beta becomes larger in another location. Thus, it must be set to adequate value in order to prevent deterioration in the beam life time. There is also a need to keep the betatron tune away from an integer resonance sufficiently.

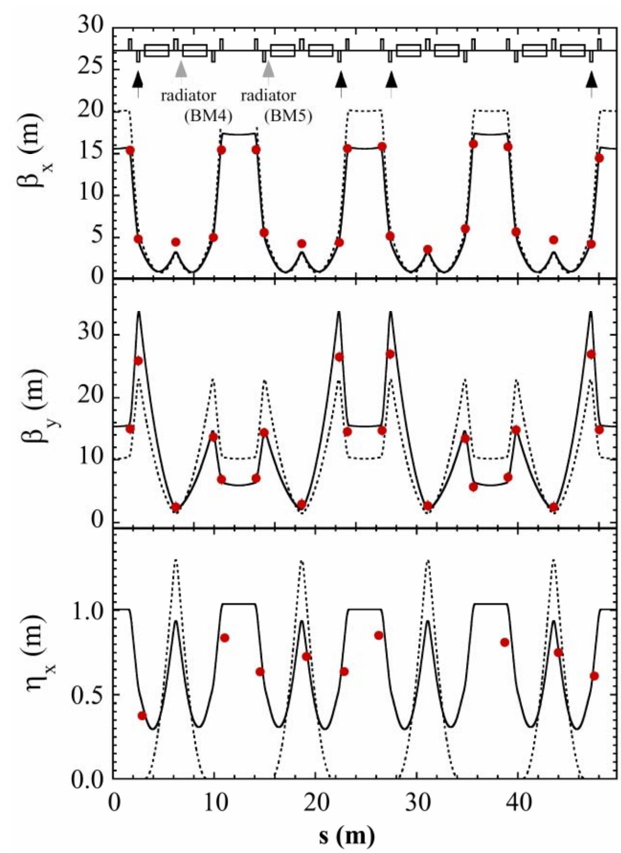

Figure 4: Modified lattice functions (solid line) with measurements (plots). Dotted lines show the original lattice functions (four-fold symmetry). Gray arrows: radiator locations, four black arrows: locations of defocus magnet connected with shunt module.

To realize the required optics, four defocus magnets were connected with shunt modules (Takasago co. ltd. FK-200L) which were able to absorb 40 amperes in maximum (see Fig. 4). These shunts are operated in a pattern mode; they start to absorb their currents by a trigger just after the completion of beam acceleration and stop before next beam injection.

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A measurement of the local beta functions and dispersion was performed for this modified optics and consistent with an expectation as shown in Fig. 4. A result of the electron beam profile by the tracking simulation with the modified optics is shown in Fig. 5. The wire fork was also replaced by a new one with wider gap of 30mm. Consequently, it is expected that the scattered electrons does not hit the wire fork any more.

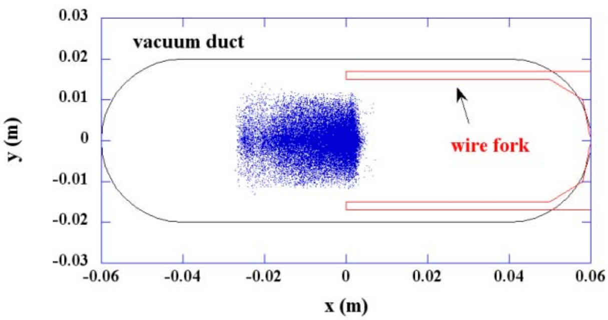

Figure 5: Electron beam profile after scattering for the modified lattice (simulation).

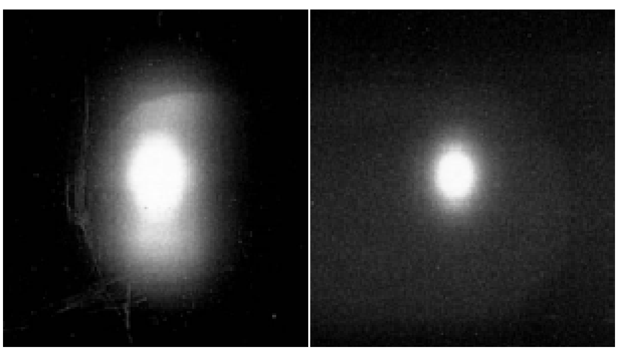

Figure 6: Observed gamma-ray beam profile (left: before modification, right: after).

Fig. 6 is the observed profiles of extracted gamma-ray beam before and after the modification. Before the modification, there were some ghost-like components above and below the actual component. On the other hand, one can see small and clear profile after the modification. The tagging efficiency for tagged gamma-rays was also improved. Fig. 7 shows the tagging efficiency versus tagger channel which corresponds to the gamma-ray energy. The efficiency was very poor before due to a lot of background in tagger detector, however, it was much improved (~80%) after the modification.

CONCLUSION

A 1.2 GeV STB ring has been routinely operated at LNS in Tohoku University. In the booster-storage operation with newly prepared gamma-ray beam line, there were serious problems in tagging efficiency and gamma-ray profile. It was found that some fractions of circulating electrons were deflected in the target wire due to Coulomb scattering without significant loss of their

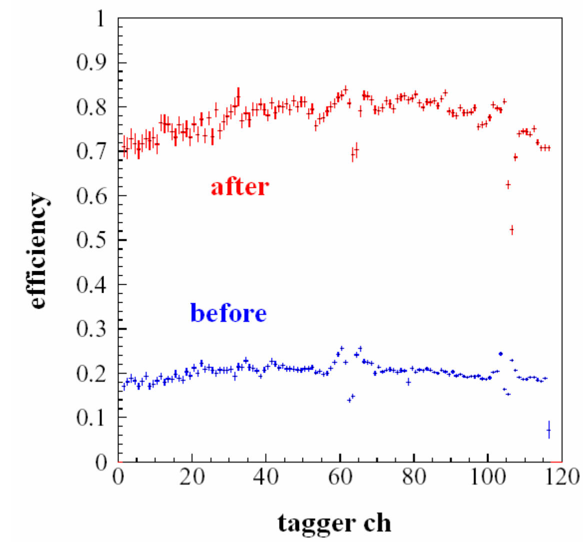

Figure 7: Tagging efficiency of gamma-rays.

energy, and thus the scattered electrons hit the chamber walls and supports of the target wire during further turns. Consequently, those electrons caused a lot of background and a degradation of gamma-ray beam quality. In order to overcome this situation, the lattice functions of the ring were modified by introducing the shunt modules to some defocus magnets. Finally, the tagging efficiency and gamma-ray profile were both improved very well. The same manner was also applied for lower energy operation of 930 and 720 MeV to utilize the gamma-rays in wider energy range. Although it was successfully realized to operate with the lower beam energy, such operation was obviously disadvantage because of the effects of ion trapping, beam instability and so on. More improvements with respect to the vacuum system and beam stability must be done to utilize the gamma-ray with good quality.

It is a very simple way to employ the internal target wire for generating the high energy gamma-rays. However, one has to take into account the effect of scattered electrons in such operation. In order to get the gamma-rays with much better quality, the scattered electrons should be lost to prevent those from going back to the radiator again. On the other hand, the beam life time could be drastically worth for such situation. As a result, one shall have to compromise the gamma-ray quality with the reasonable beam life, and this point of view seems to be an essence for this method.

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