IEEE Transactions on Nuclear Science, Vol. NS-32, No. 5, October 1985

HIGH DUTY CYCLE, TAGGED AND POLARIZED PHOTON BEAM FROM 1.3 GEV ELECTRON SYNCHROTRON

K. Yoshida, T. Fukushima, M. Kasuya, T. Kitami, T. Miyachi, M. Mutou, H. Tsujikawa, and K. Watanabe
Institute for Nuclear Study, University of Tokyo
3-2-1 Midori-cho, Tanashi-shi, Tokyo 188, Japan

K. Baba*, I. Endo, T. Sugitate, and Y. Sumi
Department of Physics, Hiroshima University
Higashisendamachi, Naka-ku, Hiroshima 730, Japan

K. Takahashi
Faculty of Technology, Tokyo University of Agriculture and Technology
Nakamachi, Koganei-shi, Tokyo 184, Japan

T. Maki
University of Occupational and Enviromental Health
Iseigaoka, Yawatanishi-ku, Kitakyushu-shi 807, Japan

Abstract

A new tagged-photon beam channel is under construction at the electron synchrotron laboratory of Institute for Nuclear Study, University of Tokyo. In this channel, the duty cycle of the extracted electron beam is expected to be 20% so that the effective tagged-photon intensity will be as high as 2 x 10^6 photons/second. To obtain the high-duty-cycle beam, magnetic fields of the components in the beam extraction system and in the beam transport system are modulated so as to follow the change of the magnetic field of the synchrotron. By introducing a large-acceptance spectrometer for the experiments with the tagged photon beam, the data-taking efficiency will be markedly improved. These high-duty beam will enable us to perform the experiment with the tagged and polarized photon beam by using a single crystal for the radiator material in the tagging system.

Introduction

At the electron synchrotron laboratory of INS, a photon tagging system has been operated since 1972 [1]. The electron beam is extracted by the absorber (Piccioni) method [2-4] and transported to the radiator in the photon tagging system, where the bremsstrahlung photon is radiated. By measuring the energy of the recoiled electron, we can define the energy of the emitted photon with an accuracy of about ± 7 MeV. The intensity of the tagged photon beam is limited to 2×10^5/second, because of the accidental coincidence rate between the tagging counters and the counters in the spectrometer. To increase the effective intensity, it is essential to increase the duty cycle of the electron beam. In the present beam extraction system, the kicker magnets are excited with the trapezoidal current pulses with flat tops of 3 msec. The energy of the electron in the synchrotron, however, changes by 1% in the above 3 msec time period. Since the momentum acceptance of the beam channel is 0.3%, the beam extraction can continue for only 1 msec, which leads to a beam duty cycle of 2% [5].

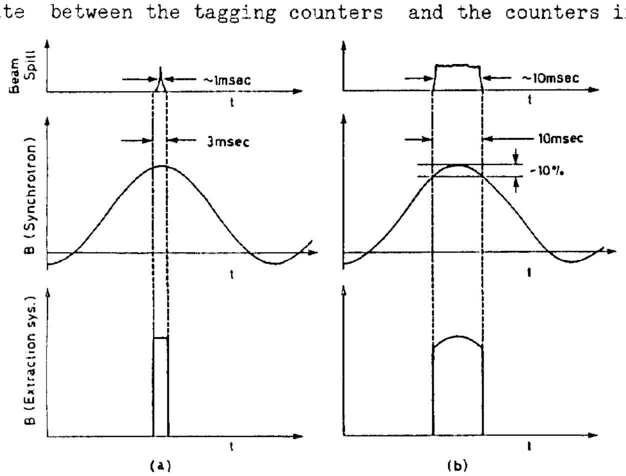

Fig. 1. Electron beam extraction by the current pulse with a flat top (a) and with a modulated top (b).

*Present address : Syudo University, Hiroshima, Japan.

One of the most simple way to prolong the beam extraction period is to modulate the fields of the kicker magnets so as to meet the field variation of the synchrotron magnet. In this way one can increase the duty cycle of the beam extraction, in principle, as desired. This situation is schematically shown in Fig.1. However, in this method, the energy of the extracted electron beam changes with time. For example, the energy change during 10 msec, which corresponds to a duty cycle of 20%, is about 10% as shown in Fig.1. While these energy variation in a burst is not allowable for usual experiments, it is no problem for tagged photon experiments, since the time dependence of the electron energy is always definitely known from the magnetic field of the synchrotron and we can measure the moment when the photon-induced reaction occurrs.

By employing the above scheme, we are constructing a new tagged-photon beam channel [6-7]. Current pulses of 10 msec for the kicker magnets are technically feasible, and we will be able to attain the duty cycle of 20%, which is ten times higher than the present system and effective photon intensity will reach at the level of 2 x 10^6/second. Data-taking efficiency will be further improved by installing a large-acceptance spectrometer which consists of a circular dipole magnet and drift chambers surrounding the target at the center of the magnet.

By using a single crystal for the radiator in the photon tagging system, one can, in principle, produce the polarized and tagged photon beam.

Technical problems for realizing the above scheme are described in the following sections.

Electron Beam Extraction

The electron beam intensity in the INS synchrotron is typically 100 mA in terms of the circulating current, which corresponds to 10^{12} electrons/second. Necessary electron beam intensity to produce tagged photons of 2 x 10^6/second is below 10^9 electrons/second. These low-intensity electron beam can be extracted by the absorber method as employed so far, which is shown in Fig. 2. Electrons which pass through the energy absorber take their orbit inward, are kicked outward by the kicker magnet I (KMI), and they are extracted by the kicker magnet II (KMII) from the synchrotron.

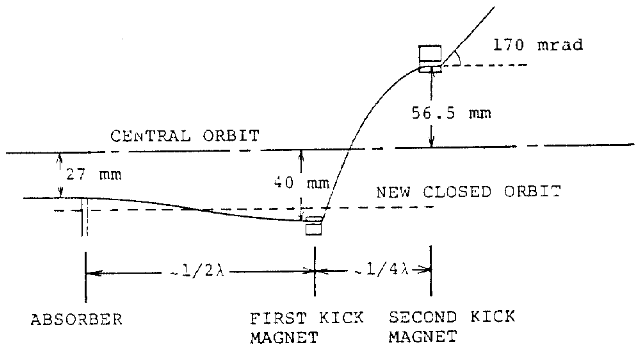

Fig. 2. Electron beam extraction by the absorber method [5].

The kicker magnets are remodeled to have cooling capability for increased duty cycle of 20%. Parameters for the kicker magnets are shown in Table 1. As mentioned in the previous section, KMI and KMII are

Table 1. Parameters of the kicker magnets.

	KM I	KM II
Effective length (cm)	19	60
Field Strength (kG)	4.5	11.5
Bending Angle (mrad)	22	172
Vertical Aperture (mm)	6	7.5
Horizontal Aperture (mm)	20	25
Peak Excitation Current (A)	2,000	8,000
Current Pulse Width (msec)	10	10
Excitation Repetition (Hz)	21.5	21.5
Required Field Accuracy (%)	±1.0	±0.3

excited by pulsed currents whose wave forms are similar to the excitation curve of the synchrotron around its peak. The INS synchrotron is excited by resonance current biased by dc as shown in Fig.1. Thus the current pulse for the kicker magnet is generated based upon a resonance discharge circuit. The block diagram of the pulser is shown in Fig.3.

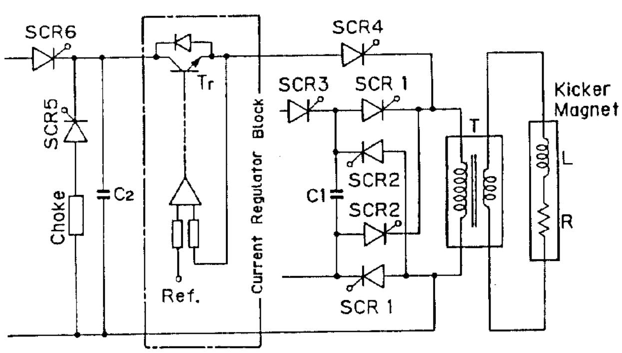

Fig. 3. Block diagram of the current pulser for kicker magnet.

The current loop including the capacitor C1 generates quickly raising / dropping currents. The discharge current from C2, on the other hand, produces the current to form the pulse top. The capacitance C2 is so chosen that the wave form of the discharge current is as close as possible to the field variation of the synchrotron magnet. Their agreement, however, can not be perfect because the full-swing sine wave of the synchrotron magnet current is approximated by a half-wave of the resonance discharge current, and furthermore the discharge current has a droop due to the resistance of the load. Nevertheless this circuit can satisfy the accuracy requirement of 1% for the KMI. As for the KM II, however, we need to introduce an additional current regulator consisting of transistors to meet the accuracy requirement of 0.3%.

Working characteristics of the current pulser mentioned above have been examined by using a model circuit. It is seen in Fig. 4 that the fundamental

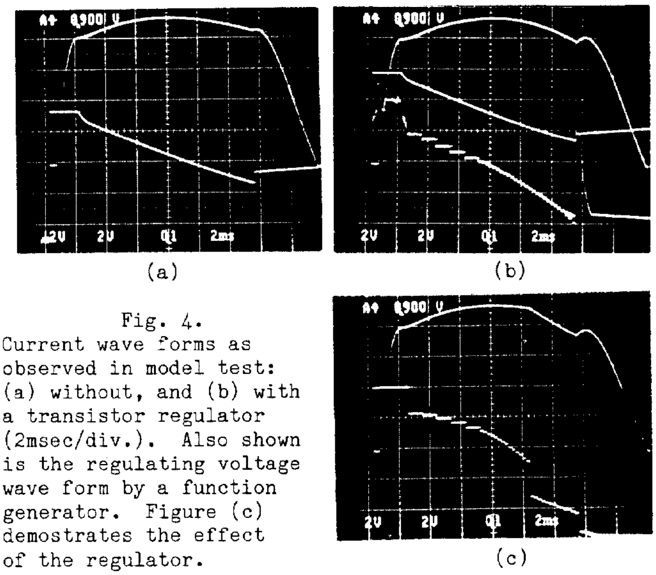

Fig. 4. Current wave forms as observed in model test: (a) without, and (b) with a transistor regulator (2msec/div.). Also shown is the regulating voltage wave form by a function generator. Figure (c) demostrates the effect of the regulator.

current pulse can be formed as expected and a slight asymmetry in the wave form can be adjusted by a current regulator. Through this model test, the feasibility of a current pulser that can generate the pulse of 10 msec width, 8,000 A peak current with 0.3% accuracy has been ascertained.

Extraction efficiency of the above system has been calculated by a Monte Carlo method to be about 10%. As a characteristic of the absorber method, a major part of the circulating electrons in the synchrotron can be used for producing the bremsstrahlung beam at the internal radiator in the other straight section.

Beam Transport System

The extracted electron beam is transported to an experimental area. This beam transport system can be composed of two bending magnets and a quadrupole doublet. In contrast to the usual monochromatic beam, the present beam to be transported changes its energy with time by 10% during 10 msec interval. To transport this beam without dispersion due to energy variation,

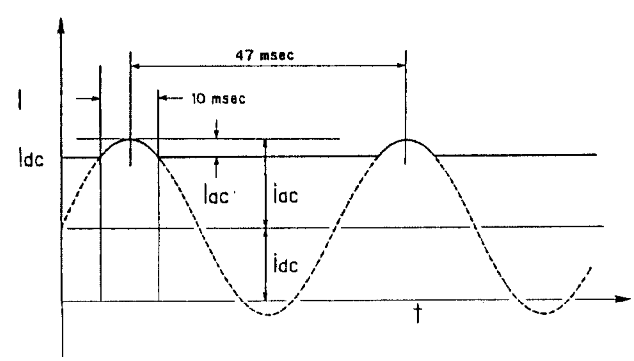

Fig. 5. Excitation current for bending magnets in the beam transport. Dashed line represents the excitation curve of the synchrotron.

we have employed a method to use bending magnets excited by modulated current as shown in Fig. 5. To the usual dc, a wavy current which has a similar shape to the excitation current of the synchrotron magnet (indicated by dashed line in the figure) is superposed. This modulation current is generated by a discharge of a capacitor. Fine adjustment of the wave form is made through a transformer installed in the current loop. In order to avoid eddy current effects, the iron yokes of bending magnets are made by lamination. On the other hand, quadrupole magnets can be excited with dc because the aberration caused by the 10% energy variation is small enough for the present experimental program.

An optimized composition of the beam transport system is shown in Fig.6. This system focuses the beam on the radiator of the photon tagging system located

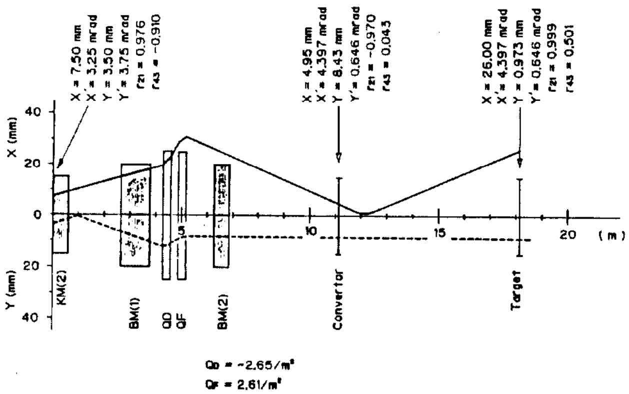

Fig. 6. Optics of the beam transport system.

11m downstream from the exsit of the kicker magnet. The alternating bend system excited by a common power supply can reduce the accuracy requirement for the excitation current to 0.3%.

The paremeters of beam transport magnets are shown in Table 2.

Table 2. Parameters of beam transport magnets.

	B.M.I	B.M.II	Q_d	Q_f
Effective Length (cm)	120	60	30	30
Field Strength (kG)	11.5	11.5		
Focusing Force ($/m^2$)			-2.65	2.61
Bending Angle (mrad)	344	172		
Vertical Aperture (mm)	32.4	32.4		
Horizontal Aperture (mm)	50	50		
Peak Exciting Current (A)	660	660		
Peak Exciting Voltage (V)	600	300		
Current Accuracy (%)	0.3	0.3		

Production of Polarized Photons

By substituting a single crystal for the amorphous radiator in the photon tagging system, one can produce tagged and polarized photons through Uberall-Diambrini effect. For this purpose, the radiators are mounted on a goniometer. The degree of polarization depends critically on the energy and angular spreads of the incident electron beam. It is expected that the energy and the angular spreads can be suppressed to ±5MeV and ±2mradian, respectively, by trimming the electron beam with collimators installed in the beam transport.

The calculation of the polarization for this case with an electron energy of 1200 MeV is shown in Fig.7 [8]. Although the polarization is around 20%, we can select photons in the energy region where the enhancement by Uberall-Diambrini effect appears, thus eliminating the background contributions due to unpolarized photons in other energy regions. This merit of photon tagging will compensate the insufficient polarization.

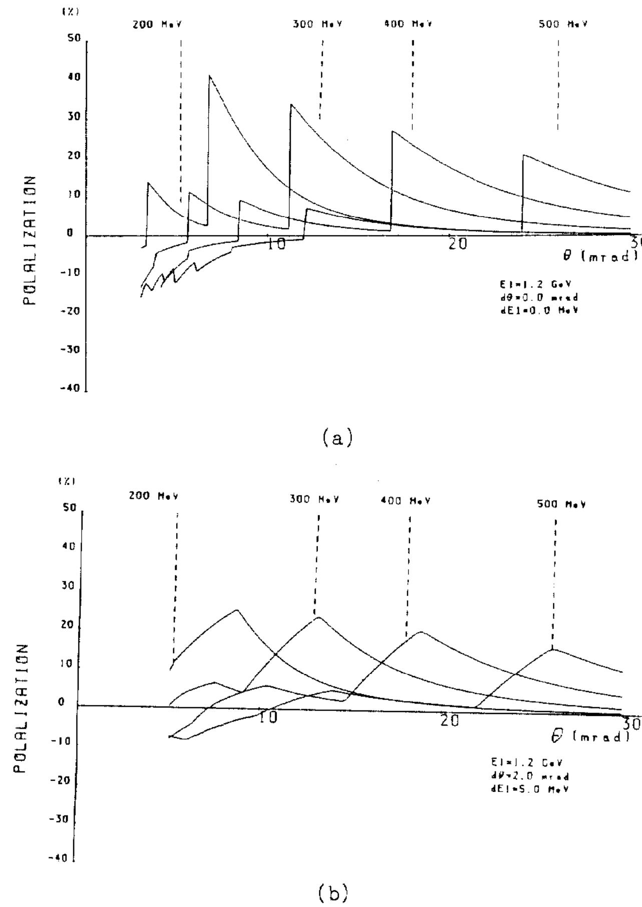

Fig. 7. Polarization of photons emitted by the 1200 MeV electron beam passing through Si crystal in the (001)-plane. The electron beam has (a) no energy and angular spread and (b) an energy spread of ±5 MeV and an angular spread of ±2 mradian [8].

Acknowledgments

The authors are grateful to Prof. S. Kato for his encouragement to carry out this work. They express their thanks to Prof. H. Okuno for his valuable discussion and critical reading of the manuscript.

References

[1] S. Arai et al., Japan. J. Appl. Phys. 14, 95(1975).
[2] O.Piccioni et al., Rev. Sci. Instrum. 26, 232 (1955).
[3] S. Kawasaki and K. Huke, Japan. J. Appl. Phys. 6, 231(1967).
[4] K. Huke et al., Japan. J. Appl. Phys. 24, 231 (1967).
[5] S. Asaoka et.al., INS-TH-147, Institute for Nuclear Study, University of Tokyo (1982) (in Japanese).
[6] Proc. of the Workshop on Tagged and Polarized Photon and Its Applications, Hiroshima University HUPD-8405(1984).
[7] T. Fukushima et. al., Proc. of the 5th Symposium on Acc. Science and Tech., KEK, p. 178 (1984).
[8] H. Kinoshita and S. Kasai, Proc. of the Workshop on Tagged and Polarized Photon and Its Applications, Hiroshima University HUPD-8405(1984).