

GENERATION OF HIGH DUTY CYCLE, TAGGED AND POLARIZED PHOTON BEAM

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ABSTRACT

A new photon tagging system is under construction at Institute for Nuclear Study, University of Tokyo. In this system, the duty cycle of electron beam extraction from the synchrotron is increased up to 20%, so that the effective intensity of the tagged photon beam will be ten times higher than in the present system. This enables us to produce quasi-monochromatic and polarized photon beam by substituting a single crystal for the ordinary radiator materials to produce bremsstrahlung in the tagging system.

INTRODUCTION

At INS 1.3 GeV electron synchrotron, a photon tagging system has been operated since 1972 (1). As the necessary electron intensity for photon tagging is weak, the electron extraction from the synchrotron is made by absorber (Piccioni) method shown in Fig. 1 (2).

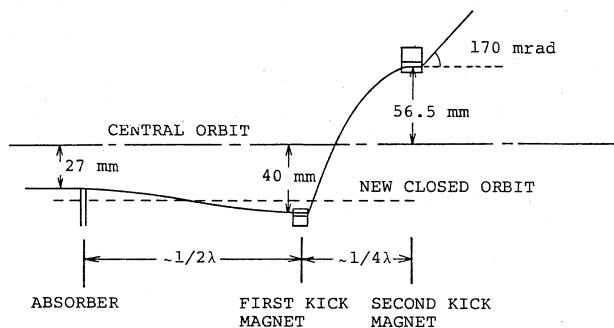


Fig. 1 Electron extraction by absorber method.

Those electrons which pass through the energy absorber take their orbits inward, enter into the first kicker magnet (KMI), are kicked towards the second kicker magnet (KMII), and are ejected outside the synchrotron. KMI and KMII are excited by pulsive currents with 3 msec flat tops. This, however, does not mean that the extraction period is 3 msec, since the magnetic field of the synchrotron, and hence the energy of circulating electrons, varies with time due to resonance excitation of the synchrotron magnet, and meets the magnetic field of the kicker only momentarily. The practical extraction period is about 1 msec determined by the momentum acceptance of the extraction system, which corresponds to a duty cycle of 2% (see Fig. 2 (a)).

Electron beam for photon tagging is limited to a certain intensity for suppressing accidental coincidences. The acceptable electron beam intensity is pro-

portional to the beam duty cycle. Thus a duty cycle as high as possible is desired for improving experimental accuracy.

A straightforward method to increase the beam duty cycle of the synchrotron is to provide the synchrotron with flat magnetic field during the beam extraction. The power supply for such an excitation mode, however, will be expensive, and the necessary excitation voltage is so high that the attainable energy is limited to nearly 900 MeV (3).

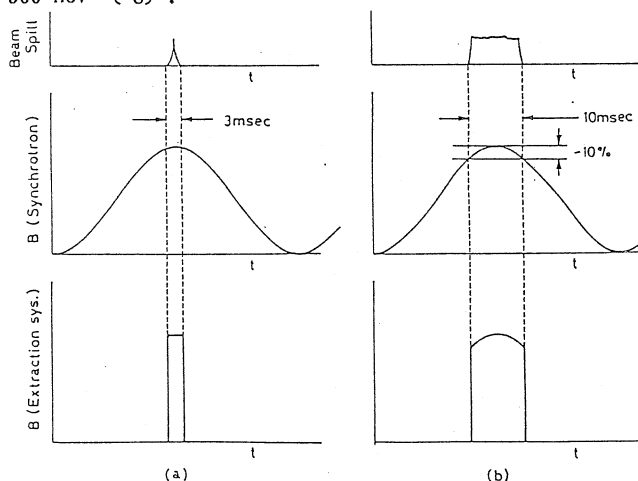


Fig. 2 Wave forms of the magnetic field of (a) present extraction system and (b) new system.

An alternative way to extend the beam extraction period is to make the wave forms of the pulsed magnetic field of the extraction system to follow the sinusoidal field variation of the synchrotron (see Fig. 2 (b)). By extending the pulse width of the kicker magnet, we can, in principle, obtain the electron beam with a duty cycle as high as desired. In this case, the energy of extracted beam changes sinusoidally with time. This is unsuitable for usual purposes of beam utilization, but not inconvenient for photon tagging experiment since we can still determine the photon energy by measuring the incident electron energy in addition to the energy of the electron recoiled from the radiator.

By employing above principle, we are constructing a new photon tagging system. The pulse widths of the kicker magnets are extended to be 10 msec, with which we can obtain the electron beam with a duty cycle of 20%, ten times higher than the present level. The electron energy variation in 10 msec is about 10% of the end point energy, which can easily be covered by usual tagging method.

This intensified beam allows us to perform experiments with tagged and polarized photons by substitut-

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ing a single crystal for the ordinary radiator materials of the photon tagging system.

Technical problems on carrying out above scheme, and some results of model tests are discussed below.

ELECTRON BEAM EXTRACTION

The peak excitation currents of KM I and KM II are 2000 A and 7500 A, respectively. The current pulses must have sinusoid-shaped tops similar to the peak of DC-biased AC current of the synchrotron, and a width of 10 msec, as schematically shown in Fig.2 (b). These pulses are generated by resonant discharging circuits followed by a pulse transformer, shown in Fig.3.

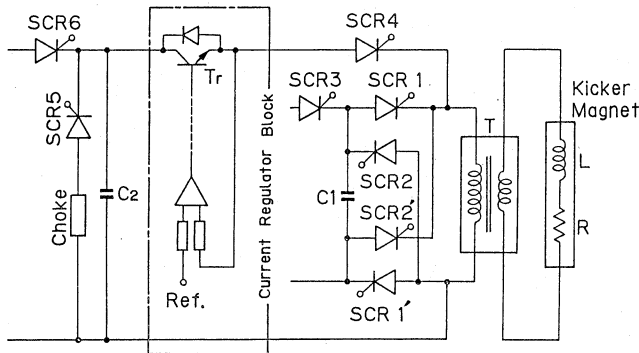


Fig. 3 Current pulse generator for kicker magnets.

Triggering SCR1 and SCR1', the electric charge stored in capacitor C1 makes rapidly increasing current. When the current reaches at its maximum, SCR4 is turned on, and a resonant current whose time constant is determined by the capacitance C2 and the inductance of the load is generated, SCR1 and SCR1' being automatically turned off. 10 msec after gating SCR4, the SCR2 and SCR2' are turned on, and the current steeply goes down, the SCR4 being automatically closed. The current during the SCR4 is open excites the magnetic field for extracting electron beam from the synchrotron. Numerical calculation shows that we can make the exciting current correspond to the magnetic field of the synchrotron with an accuracy of the order of 10^{-3} by carefully adjusting C1 and C2, if the load is purely inductive.

However, the loads have resistances of about $0.5 \text{ m}\Omega$, which can not be ignored compared with the inductance of about $3.5 \mu\text{H}$. In addition, the magnetic field of the synchrotron deviates from a sinusoidal variation due to the saturation of the permeability of the iron core in high energy operations. In order to correct these effects, we must install a current regulator in the current loop including the capacitor C2.

On the other hand, necessary accuracies for respective kicker magnet excitations have been estimated by tracing the electron orbit in the synchrotron. The remarkable feature of present beam extraction scheme is as follows. The energy absorber of the Piccioni system produces large energy and angular spreads in the electron beam passed through it. For example, energy loss is $2.5 \text{ MeV} \pm 15\%$ and the angular spread is $\pm 3 \text{ mrad}$ for 900 MeV beam. Since the electron beam for the photon tagging system should have a small emittance and narrow energy spread in order to suppress background and/or to produce coherent bremsstrahlung in a single crystal, a very small fraction of these electron is finally selected. These situations impose a stringent accuracy requirement on KM II, and a moderate one on KM I. Accuracies to keep the beam stability at the photon tagging system within 10% are estimated to be 0.3% for KM II and 2% for KM I, respectively. Thus the current regulator is not required for KM I. Much atten-

tion, on the otherhand, should be paid on the pulse generator for KM II in respects of both current capacity and its accuracy.

BEAM TRANSPORT

The energy of the electron beam extracted from the synchrotron varies with time by 10% in 10 msec. This beam must be transported to photon tagging system along a line. It is needed to bend the beam twice among the KM II and the tagging system. To cancel the dispersion at the bending magnets, they should be composed either by AC magnets which are excited so as to follow the excitation curve of the synchrotron, or by DC magnets making an achromatic bend. Although DC magnets are easier than AC magnets both in fabrication and operation, no reasonable focusing elements for the achromatic bend system have been found by beam trace calculation. Thus we have employed a beam transport system by AC magnets. Since the excitation currents are not so high as for the kicker magnets, around some hundreds amperes, we are going to make it by a superposition of DC and AC whose amplitude is nearly 10% of the DC, as shown in Fig.4.

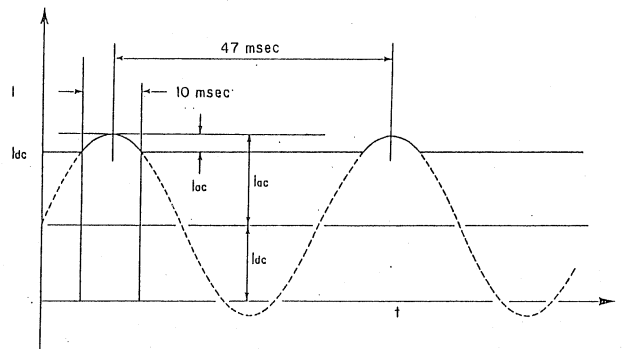


Fig. 4 Exciting current for bending magnet in beam transport system. i_{dc} and i_{ac} correspond to DC and AC of the synchrotron magnet, respectively.

Two bending magnets are excited by a series current.

The focusing quadrupole magnets excited by DC introduces chromatic aberration and hence an oscillation of the emittance corresponding to the energy variation of the beam. The oscillation amplitude is estimated to be about 20% of the central value, and we decided to go tentatively with this condition.

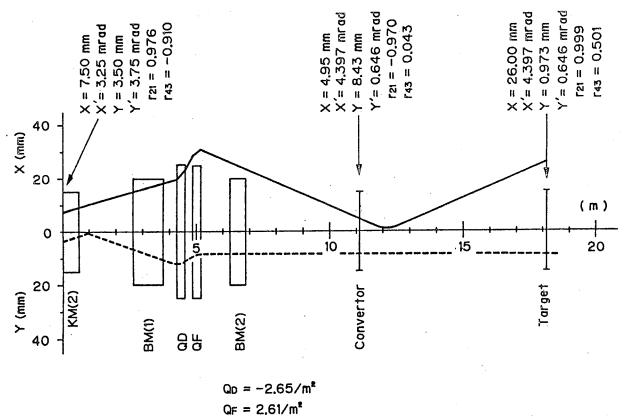


Fig. 5 Beam trace calculation of transport system.

An optimized composition of the beam transport system is shown in Fig. 5. Beam trace calculation shows that the alternating bend system reduces the accuracy requirement on the exciting current, which is common for two magnets, to be about 0.3%.

An overall arrangement of the beam transport and photon tagging system is shown in Fig. 6.

PRODUCTION OF POLARIZED PHOTONS

To produce polarized photons by Uberall-Diambrini effect in a crystal, the energy and angular spread of incident electron beam should be small. By trimming the beam to have a energy spread of ± 5 MeV and an angular spread of ± 3 mrad, the intensity of the resultant beam will be 10^8 /sec, and expected photon polarization will be as shown in Fig. 7 (4). By photon tagging method, we can select the photons in the energy region where the enhancement by Uberall-Diambrini effect appears, thus eliminating the background contributions due to unpolarized photons from other energy regions. This merit of photon tagging will make up for the insufficient polarizations.

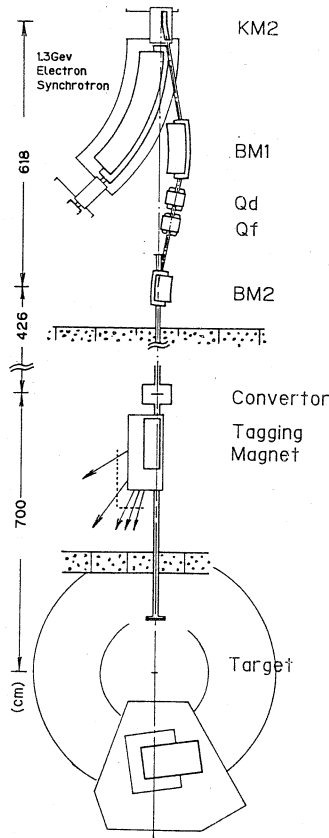
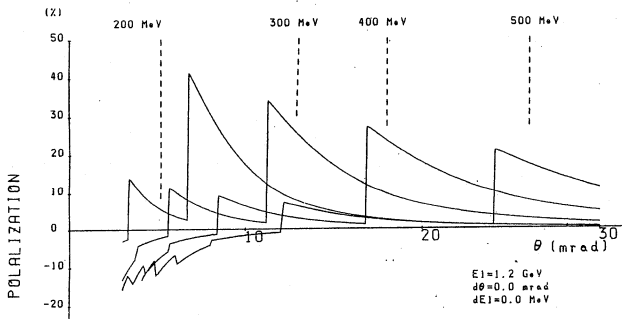
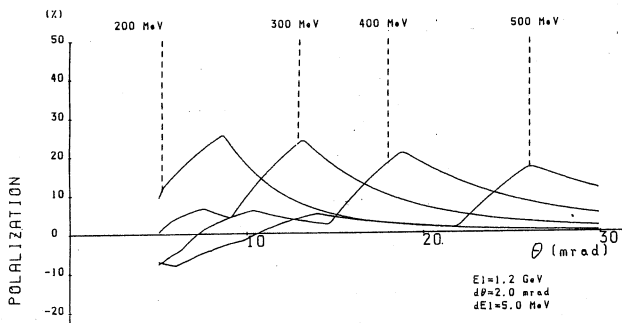


Fig. 6
Layout of beam transport and photon tagging system.



(a)



(b)

Fig. 7 Uberall-Diambrini effect by 1200 MeV electron beam with no energy and angular spread (a) and with an energy spread of ± 5 MeV and an angular spread of ± 2 mrad (b) (4).

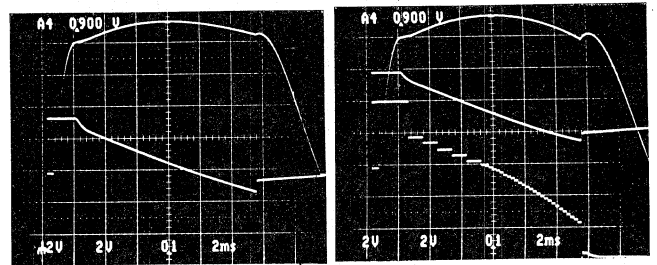
RELATED TECHNICAL PROBLEMS

rf system High duty cycle electron beam extraction can be realized only when the beam spilling by rf perturbation is well controlled. Extension of the spill time up to ± 2.5 msec has been possible in routine operation of the synchrotron (5-6). We now need to extend the spill time up to ± 5 msec. A preliminary test shows that the required spill time is obtainable by currently existing methods. For the stable operation, however, it will be needed to introduce some transversal forces on the electron beam in addition to rf-based perturbation.

Monitor and control To extract the electron beam whose energy changes with time, and to transport it toward experimental system, we must control at least three current pulses whose amplitudes are large and whose wave forms should be highly accurate. Final adjustment of these pulses will be made by observing the behaviour of the beam. Thus the monitor and control system is essential for stable operation of this beam channel.

MODEL TEST OF THE PULSER FOR KICKER MAGNET

The most critical current pulser in respects of current capacity and the wave form accuracy is the one for KM II. So a model for this pulser, provided with current regulator, has been prepared and tested. The result is shown in Fig. 8.



(a)

(b)

Fig. 8 Current Wave forms generated by a KM II model pulser without current regulator (a) and with it (b).

Working characteristics are assured to be as expected. It is seen in the figure that the wave form of discharge current without a current regulator is deformed from sinusoidal wave, while it can be adjusted by a current regulator, the control signal for which (step function) is also shown.

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REFERENCES

- (1) S.Arai et.al., Japan J. Appl. Phys. **14** (1975) 95
- (2) S.Asaoka et.al., INS-TH-147 (1982) (in Japanese)
- (3) S.Arai et.al., INS-TH-153 (1983) (in Japanese)
- (4) H.Kinoshita and S.Kasai, Proc. of the Workshop on Tagged and Polarized Photon and Its Applications, Hiroshima, HUPD-8405 (1984)
- (5) T.Katayama et.al., Japan J. Appl. Phys. **19** (1980) 2229
- (6) T.Fukushima et.al., INS-TH-137 (1981) (in Japanese)