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PRESENT STATUS OF THE 1.3 GEV ELECTRON SYNCHROTRON AT INSTITUTE FOR NUCLEAR STUDY, UNIVERSITY OF TOKYO

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ABSTRACT

The 1.3 GeV electron synchrotron at Institute for Nuclear Study (INS) , University of Tokyo has been continuously operated up to now since its completion in 1961. One of the majour experimental facilities at present is a high-duty-cycle photon tagging system for experiments in intermadiate energy region. The synchrotron beam is used also in regular injection into 300 MeV synchrotron radiation ring and other interdisciplinary researches.

HISTORY

The electron synchrotron at INS was put into operation in 1961 as the first accelerator for high energy physics in Japan [1] . The synchrotron has been actively used for these twenty-five years in particle physics and other purposes.

The maximum energy of the synchrotron was initially 750 MeV, but it was raised up to 1.3 GeV in 1965. The external electron beam has been available since 1967 [2] . The first photon tagging system in INS was completed in 1972 [3] .

The electron synchrotron as well as the experimental equipments were improved with special budget during the years from 1972 till 1979. In 1973, the vacuum system consisting of epoxi-resin doughnut chamber evacuated by oil diffusion pumps was replaced by the one with metal doughnut and ion pumps. Injector linac with design energy of 6 MeV was replaced with new 15 MeV linac in 1974 [4] . Other deteriorated parts were also replaced annually. Owing to these improvements, the performance of the machine became quite satisfactory. The maximum beam intensity has attained to 160 mA in terms of circulating current, which may be the record of the world electron synchrotrons [5] .

In 1982, the metal doughnut, made of welded stainless-steel (0.12 mm thick) bellows, was found to be seriously damaged with radiation effects, and all the modules were renewed. It is thus proved that the life of the vacuum chamber of this type will be around 9 years.

Utilization of the synchrotron orbital radiation for solid state physics was initiated just after the completion of the synchrotron. Based upon this achievement, an dedicated storage ring with operating energy of 400 MeV, SOR-RING, was completed in 1974. The synchrotron has regularly supplied electron beam to the storage ring.

STATISTICS

Operation Hours. Fig.1 shows annual operation hours and failure rates of the synchrotron for the years since the first operation. It is seen that the machine was most actively used in the years between 1968 and 1971. In these years, about 7,000 hours was scheduled to operate and 5,500 hours was actually used for physics experiments. Sudden decrease of operating hours at 1972 is due to scheduled shutdown of the machine for improvements as described in the preceding section. There were other reasons of decreasing operation hours : in the

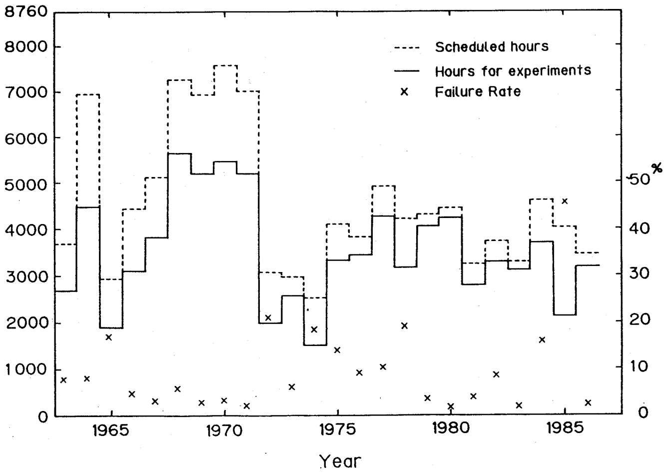
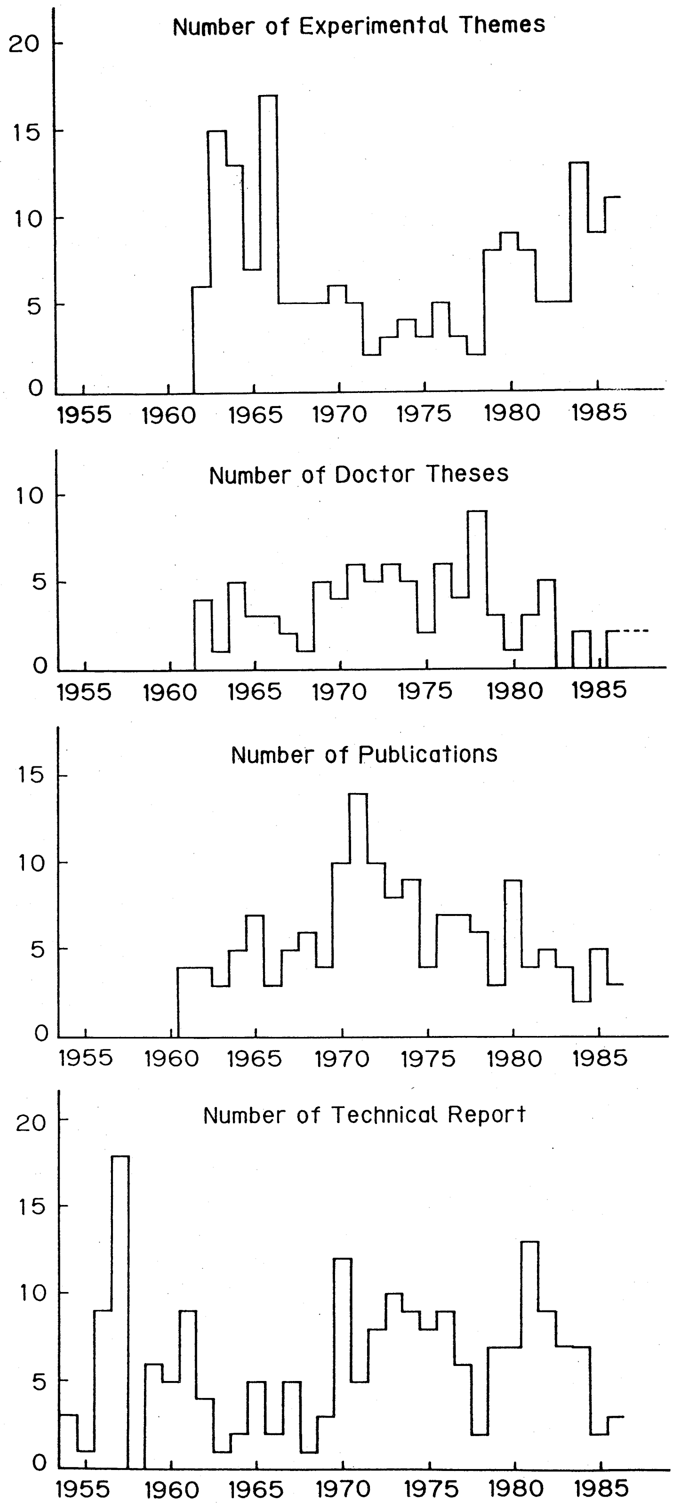


Fig.1 Annual operation hours and failure rates of the INS synchrotron.


Number of Experimental Themes

Number of Doctor Theses

Number of Publications

Number of Technical Report

Fig.2 Number of experimental themes, doctor theses and pubrications from the INS synchrotron.

first place, the so called oil shock in 1974 resulted in extraordinary increase of electricity rates and forced us to suppress operation hours, and, in the second place, the 12 GeV proton synchrotron at KEK came into operation in 1976, and the users are shared into two laboratories. In these several years, one or two majour groups can occupy beam channels of the electron synchrotron, and can perform long term experiments. On the other hand, the electron synchrotron is busy with short term experiments such as detector test, irradiation experiments and so on.

High failure rates are seen in some recent years. They are mostly attributed to deterioration of the machine components such as the synchrotron magnet and the generator system for it, which have been exposed to heavy-duty operation for more than 26 years.

Activities at INS synchrotron. Annual numbers of experimental themes, doctor theses, pubrications and technical reports are summarized in Fig.2. An overall tendency in recent years is that the numbers of doctor theses and pubrications are rather low wheras the number of experimental themes are high. The number of technical reports is in constant level. These facts may come from the recent situation of the sychrotron that it is used by small numbers of particle physics experiment groups using long machine time while it provides beams for many users who study detectors to be used in other machines or in interdisciplinary researches.

BEAM CHANNELS

Slow-extracted electron beam for photon tagging. The electron beam intensity necessary for photon tagging is not so high, nearly 10^9/sec. So electrons are extacted by means of absorber (Piccioni) method. On the other hand, high duty cycle of the beam is essentially important for photon tagging. In this beam extraction system, therefore, special power supplies are employed to extend beam duty cycle, detailed description of which is given in the following section.

This electron beam channel is often used also in detector studies.

Bremsstrahlung from internal target with full intensity. Since the electrons which are extracted by absorber method are quite a small fraction of the main beam, the bremsstrahlung from the internal target can have its full intensity. This beam is often used in irradiation experiment such as photofission of nucleus. Also this channel is busy with experimental groups for particle detector developements. In these experiments, γ-ray is usually converted into electron beam, and energy-analyzed electrons are used.

Bremsstrahlung of a faint intensity. Electrons spilling out of the main internal beam hit the inside wall of the vacuum chamber and produce weak γ-ray. This beam is introduced to a experimental area to be used in detector tests.

Fast-extracted electron beam for SOR-RING. The synchrotron supplies electrons for the 400 MeV storage ring, belonging to Institute for Solid State Physics, University of Tokyo, three times a day. Whatever the operating energy of the synchrotron is, the fast kicker magnet is triggered at the instance when the synchrotron energy reaches to 300 MeV. The rise time of the kicker magnet is 60 nsec, while the orbit time of the synchrotron is 120 nsec. So nearly a half of the circulating electrons is extracted. Since the repetition rate of the kicker magnet is 1 Hz, that of the synchrotron being 21 Hz, the extraction brings no significant disturbance to users at other channels. It usually takes 20 minutes to fill the storage ring.

Synchrotron radiation channel. This is a memorial facility where the utilization of the synchrotron radiation in Japan was initiated. Even after the completion of the 400 MeV dedicated storage ring, it had kept significance for physicists who need soft X-ray source. Presently this channel is closed.

HIGH-DUTY-CYCLE TAGGED PHOTON BEAM WITH OPTIONAL POLARIZATION

The tagged-photon beam channel is a major facility of the current electron synchrotron laboratory. In photon tagging method, the extracted electron hits the radiator giving a photon, and the scattered electron is energy-analyzed by a magnetic spectrometer. The energy of the produced photon is given by the incident electron energy subtracted by the scattered electron energy. Since the scattered electrons are individually counted by the counter, the accidental coincidence rate limits the acceptable beam intensity. Hence it is easily understood that the beam duty cycle is essentially important in getting high beam intensity.

In ordinary system to extract the beam from the synchrotron and to transport it, the beam spill time is quite short, below 1 msec corresponding to a duty cycle of 2 %. This is due to the following situation (see Fig.3). The synchrotron magnet is excited by a resonance current with a period of 47 msec, and the energy of the internal electron varies with time. On the other hand, the electron beam is extracted by kicker magnets which are excited by current pulses with flat tops, and transported through dc magnet system. Under these conditions, only those internal electrons whose energies are within the energy acceptance of the beam extraction system conbined with the beam transport system, which is usually narrow, nearly ±0.2 % corresponding to a period of 1 msec. It is clear that the way to extend the beam duty cycle is to introduce flat top to the synchrotron magnet current, or instead to excite all the magnets in the beam extraction and the beam transport system with the current which have the wave forms similar to the synchrotron magnet current. The latter method necessarily introduces the energy change in the electron beam, about 10 % in a beam spill time of 10 msec. It, however, brings no serious probrem when it is used in photon tagging, since we know the instantaneous value of the synchrotron energy, and can obtain the photon energy as,

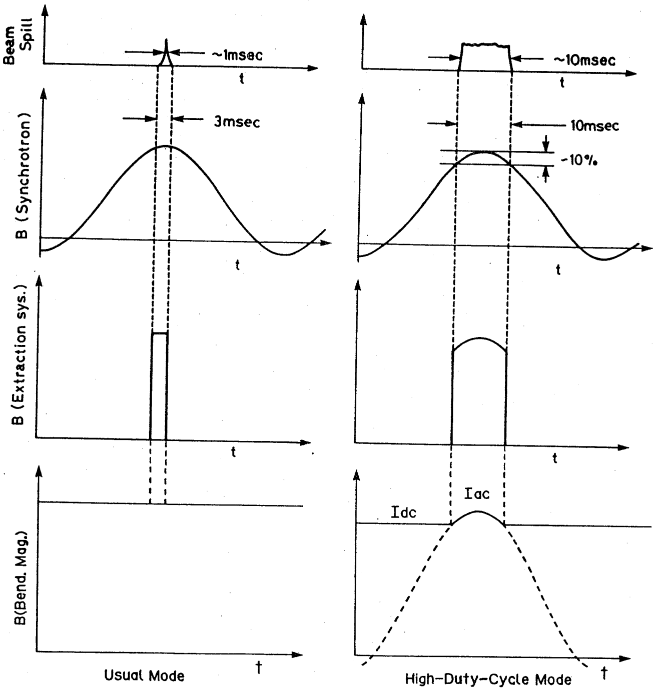


Fig.3 Principle of the high-duty-cycle tagged photon beam.

$$E\gamma = Ee\ (t) - Ee',$$

where $E\gamma$, $Ee\ (t)$ and Ee' are the photon energy, incident electron energy varying with time and the scattered electron energy, respectively. According to cost consideration we have employed the latter scheme to obtain high-duty-cycle tagged photon beam [6] .

The completed high-duty-cycle beam channel is shown in Fig.4. Those electrons whose energies have been decreased at the energy absorber take trajectory inward, and extracted by means of a pair of kicker magnets KM1 and KM2. The waveform of the pulsive current to excite KM2 is shown in Fig. 5 (a) . Necessary current for extracting electrons is, for example, 8,000 A to extract 1,200 MeV electrons, and the required accuracy of the current is ±0.2 %. This current pulse is

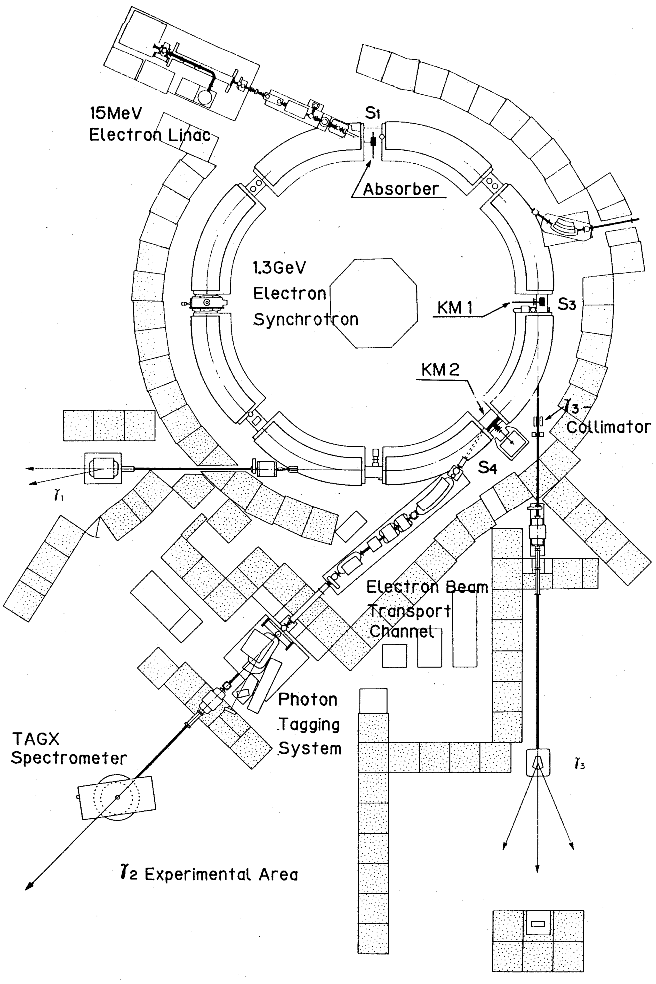
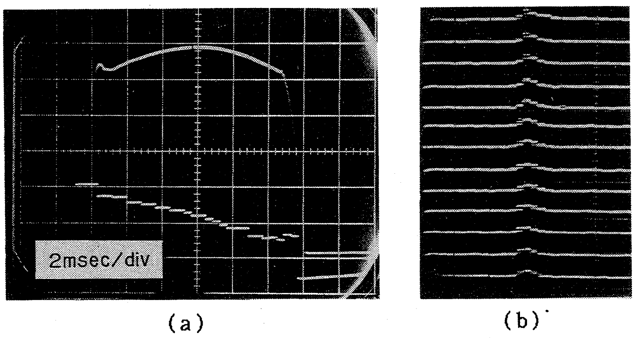


Fig.4 Beam channels of the INS synchrotron.



(a) (b)

Fig.5 The waveform of the current for the second kicker magnet (a), and the beam position as observed by multi-wire proportional chamber (b) (see text).

generated by a discharge of capacitor, regulated by a transistor circuit. A stepped waveform in the Fig. 5 (a) shows the reference signal for the regulator [7].

The extracted electron beam is transported towards the experimental area. The transport system consists of a pair of bending magnets, focusing Q-doublet, steering coils, two sets of collimator slit and so on. The bending magnets are excited by such a current that a AC-like current whose waveform is similar to the synchrotron magnet current is superposed on normal DC. Thus the electron beam whose energy is varying with time can be transported without energy dispersion. The Q-magnets, on the other hand, are excited by normal DC since the aberration produced by it can be ignored.

The position and the profile of the electron beam is monitored by multi-wire proportional chambers. Five monitors of this type are installed along the beam transport line. Any error in the excitation currents of the magnets can be found as the energy dispersion observed on the monitors.

Fig. 5 (b) shows the beam position as observed at the outlet of KM2 with the sampling rate of 1 msec. It is seen that the waveform of the current for KM2 is perfect for ±5 msec duration, as designed.

The effectiveness of the high-duty-cycle beam can be seen clearly in Fig. 6, where are shown the background components in the tagged photons when they are produced by high-duty-cycle electrons, in comparison with the one by usual electrons.

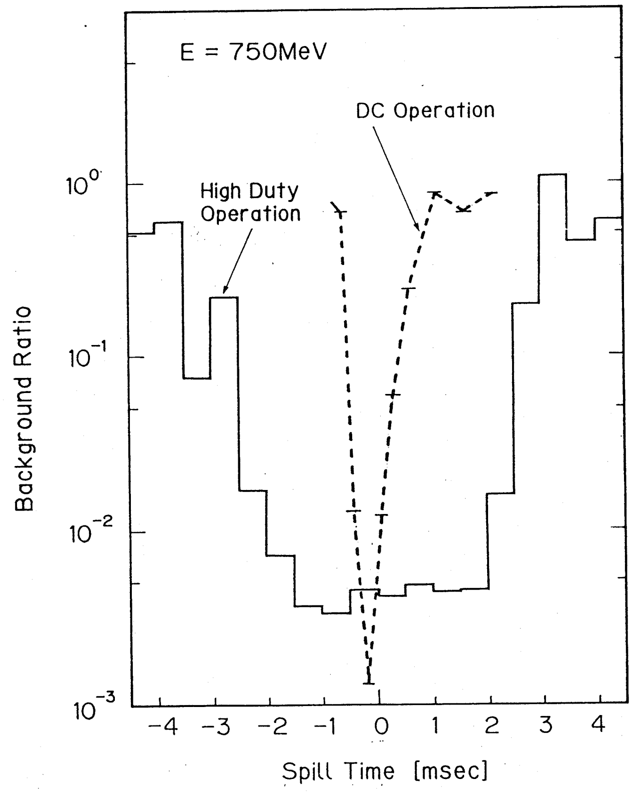


Fig. 6 Effective spill time for photon tagging.

"Usual electrons" means the ones transported by the magnets excited by usual DC. This result is obtained with imperfect waveforms of the bending magnet current. Even with this current, beam spill time in which the background contribution is not high is much extended.

When the waveform of the bending magnet current is tuned perfectly, we can expect the tagged photon beam with a intensity higher than usual by one order of magnitude. With this intense tagged-photon beam, and with the single crystal substituted as a photon radiator, we can expect to have a tagged and polarized photon beam as a probe for particle physics experiments. For this purpose, the photon radiators are mounted on a precision goniometer. Some measurements have been made with single crystals as radiators to examine coherent bremsstrahlung processes [8].

REFERENCES

[1] H. Kumagai et. al., Japanese J. Appl. Phys. 1 (1962) 66.
[2] K. Huke et. al., Japanese J. Appl. Phys. 7 (1968) 1274.
[3] S. Arai et. al., Japanese J. Appl. Phys. 14 (1975) 95.
[4] T. Katayama et. al., INS-Report 240 (1975).
[5] Catalogue of High-Energy Accelerators, CERN (1980).
[6] K. Yoshida et. al., IEEE Trans. Nucl. Sci. NS-32 (1985) 2688.
[7] M. Mutou, J. Sci. Hiroshima Univ., A-51 (1987) 187.
[8] I. Endo et. al., Proc. Int. Cof. Atomic Physics & Few Body Systems, Tokyo (1987).