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ON THE STATUS OF ACCELERATOR FACILITIES AND THEIR PROGRESS IN JAPAN

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Abstract

This article will describe accelerators and associated facilities in Japan. First two paragraphs will give a brief survey on them and the next paragraph will report the recent aspect of the KEK 12 GeV synchrotron that is the largest accelerator in Japan. Outline of the photon factory, which is under construction at KEK for the purpose of utilizing high energy accelerators for researches of various fields of natural science, will be described in the following paragraph.

1. Accelerators in Japan

Particle accelerators in Japan with energy more than 2 MeV are summarized in Table 1. They are distributed over Japan, but are fairly concentrated. Seventeen of thirty accelerators in Table 1 are located in Tokyo area and seven are in Osaka area. The total number of accelerator scientists, engineers and technicians is about 250, which is very small compared with that in advanced countries. Accelerators which are being constructed are listed in Table 2.

Table 1. Accelerators in Japan (energy > 2 MeV)

Accelerator type	Number (energy)	Main purpose of use
proton synchrotron	1(12 GeV)	High energy Physics
electron synchrotron	1(1.3 GeV)	High energy Physics
AVF cyclotron	5(26~75 MeV)	Nuclear physics & Applications
FM cyclotron	1(55 MeV)	Nuclear Physics
FF cyclotron	3(9.5~18 MeV)	Nuclear Physics & Applications
Tandem V.d.Graff	4(9.5~25 MeV)	Nuclear Physics
V.d.Graff	8(2~5.5 MeV)	Applications & Nuclear Physics
electron linac (high energy)	1(300 MeV)	Nuclear Physics
electron linac (low energy)	6(15~190 MeV)	Applications

Table 2. Accelerators in Japan (under construction)

Accelerator type	Energy	Main purpose of use
AVF cyclotron	40 MeV	Nuclear Physics & Applications
heavy ion linac	80~180 MeV C~Xe	Applications
Tandem V.d.Graff	20 MeV	Nuclear Physics & Applications
electron linac + storage ring	2.5 GeV	Applications

2. Three accelerator centers

Some of the accelerators in Table 1 are attached to universities and others are operated by governmental organisations. Among them, three accelerator centers, i.e. INS, RCNP and KEK, are operated as a kind of national laboratories and are opened to the common use of researchers from other universities or institutions. These three accelerator centers have done much for the promotion of accelerator science in Japan. INS, Institute for Nuclear Study, University of Tokyo, was established in 1955 with an FF cyclotron and an 1 GeV electron sychrotron, and was the very first institute after the War that enabled us to make studies on nuclear and elementary particle physics. It became a milestone for the further progress of this field and in fact created KEK, National Laboratory for High Energy Physics, and RCNP, Research Center for Nuclear Physics, in 1971. In Table 3 are listed accelerators operated by these three research centers.

Table 3. Three accelerator centers

Institution (Location)	Accelerator	Particle	Energy
INS (Tokyo)	AVF cyclotron	p,d,h,α	48 MeV
	FM cyclotron	p	55 MeV
	synchrotron	e	1.3 GeV
RCNP (Osaka)	AVF cyclotron	p,d,h,α	75 MeV
KEK (Tsukuba)	synchrotron	p	12 GeV
	linac + storage ring*	e	2.5 GeV

* under construction

3. KEK proton synchrotron

Outline

The KEK proton synchrotron consists of four stages of accelerators, i.e., 750 KeV preinjector, 20 MeV linac, 500 MeV booster and 12 GeV main synchrotron, as is shown schematically in Fig. 1. The construction started in April, 1971, and the first 8 GeV (original design value) beam was obtained in March, 1976, on schedule. The internal target beam for counters and the fast extracted beam for bubble chamber were opened for physics experiments in May 1977. In 1978 the energy was increased up to 12 GeV and the slow extracted beam became available to begin counter experiments with kaon beams.

Scheduling and operation statistics

The accelerator is now operated around the clock on a two-week cycle, usually 10 ~ 11 days beam-on operation and 4 ~ 3 days of maintenance and inspection. In the present schedule, Monday and Tuesday of the first week of the cycle is for the maintenance and the beam-on operation starts on Wednesday and continues untill Saturday next week. Last three or four eight-hour shifts of the cycle are used for the accelerator studies for improving beam characteristics. In most of these machine studies the full intensity beam is not required and a few pulses from the booster are injected into the main ring instead of the normal nine-pulse injection so as to keep the level of the residual radio-

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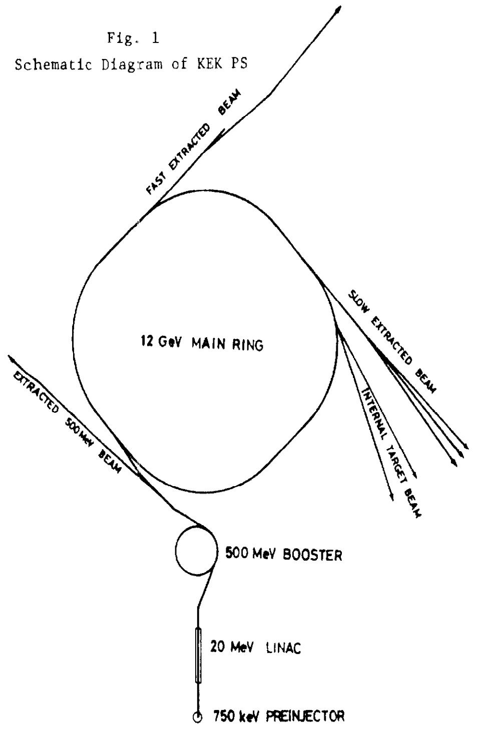
activity as low as possible.

Fig. 1
Schematic Diagram of KEK PS



Long shut-downs have been scheduled twice a year, in summer (August-September) and in spring (March-April). These shut-downs have been provided mostly for construction of new facilities and equipments around the accelerator. Typical examples are as follows:

Summer 1977 :	Construction of the slow extraction system and the primary beam line, and construction of 500 MeV beam line for the booster beam utilization facility.
Spring 1978 :	Buildup of the main ring power supply and water-cooling plant to increase the energy up to 12 GeV
Summer 1978 :	Construction of two kaon beam lines.

The operation statistics of the KEK PS is illustrated in Fig. 2. Because of two long shutdowns, the total operating hours is limited to ~ 3500 hours per year so far. In recent runs, about 75 % of the total operating time is used for physics experiments. One should note that the accelerator has worked with great reliability and stability so that the accelerator failure is less than 10 %. In the early stage of operation, the booster RF topped and the linac RF and the beam transport system followed in the ranking of the system down times. Recent statistics show that machine troubles take place quite uniformly throughout the accelerator complex.

Accelerator performance

Recent data on accelerator operation are given in Table 4.

Table 4. Accelerator Performance

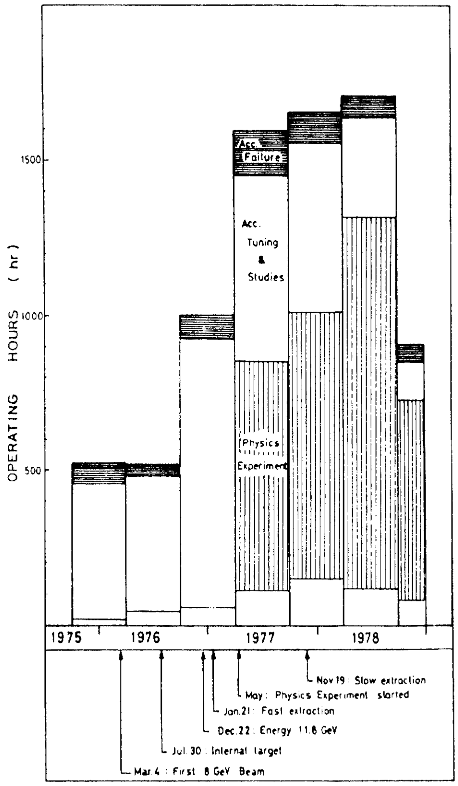
Preinjector
Energy: 750 KeV
Current: 250 mA
Emittance (Normalized): 3π mm·mr (90 %, 250 mA)

Linac
Energy: 20 MeV
Momentum Spread ($\Delta p/p$): ± 0.5 %
Current: 140 mA
Emittance (Normalized): 5π mm·mr (90 %, 140 mA)

Booster
Energy: 500 MeV
Momentum Spread ($\Delta p/p$): ± 0.3 %
Intensity: 6×10^{11} ppp
Emittance: Horizontal = 30π mm·mr (90 %, 5×10^{11}ppp)
Vertical = 15π mm·mr
Injection: Stacked Current = 300 mA (1.2×10^{12}ppp)
Captured Current = 160 mA (6.5×10^{11}ppp)

Main Ring
Energy: 8 ~ 12 GeV
Momentum Spread ($\Delta p/p$): ± 0.1 %
Intensity: 2×10^{12} ppp
Slow Extracted Beam Emittance:
Horizontal = 8π mm·mr (90 %, 12 GeV)
Vertical = 6π mm·mr

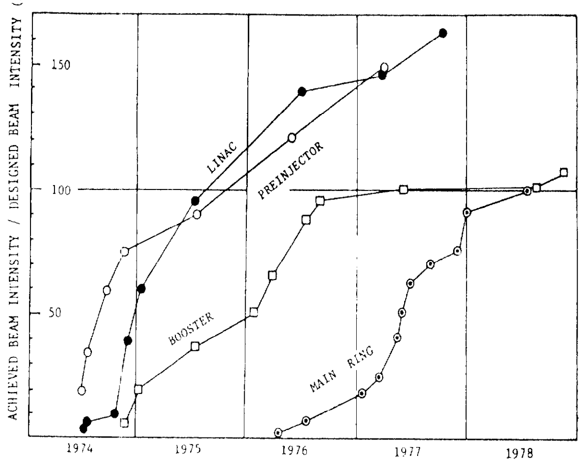
Fig. 2 Operation Statistics of KEK PS



The growth of the beam intensity is demonstrated in Fig. 3. The initial operation and succeeding progress of the KEK PS were already described in papers given by T. Nishikawa and T. Kamei.1~2) The gradual increase of the beam intensity was achieved by an integration of small improvements, as it is the case in other high energy accelerators. This report picks up some of them which have resulted in a significant rise of the beam intensity.

The booster is operated at the repetition rate of 20 Hz and, in normal operation. , about 80 mA of proton beam from the linac is injected in each cycle into the booster ring by the multi-turn injection method. Immediately after each injection, we are able to observe at least six turns of circulating protons which is equivalent to 300 mA or 1.2×10^{12} protons. However there had been considerable losses of the proton beam during one milisecond after the injection and around

Fig. 3 Growth of Beam Intensity



DESIGNED INTENSITY

PREINJECTOR	200 mA
LINAC	100 mA
BOOSTER	6×10^{11} ppp
MAIN RING	2×10^{12} ppp

the final stage of acceleration (23 ~ 25 ms). Then it was believed that the former loss was due to the lack of the RF voltage, i.e., the size of the RF bucket was too small to catch protons efficiently; and an additional RF station was installed in 1977.

This did not contribute immediately to the increase of beam intensity, but this additional RF was found to play an important role as a stand-by RF station in a long continuous run. The other beam loss around 23 ~ 25 ms was not easily understandable at first, but soon it was proved that the loss was caused by the instability due to coherent oscillation, which was finally suppressed by the use of sextupole and octupole correction magnets. On 29 November, 1978, the booster beam intensity increased to 6.5×10^{11} ppp exceeding slightly the design value of 6×10^{11} ppp. This was achieved by the following improvements:

(1) RF voltage was increased up to 17.5 KV (at the maximum) from 10 KV, by the simultaneous operation of two RF stations.

(2) Fine tuning and improvement of injection: Because of the multi-turn injection, the capture efficiency is quite sensitive to the injection condition. The pulse width of the injected 20 MeV beam was initially 10 ~ 15 μs; however a shorter pulse of ~ 5 μs width increased the beam intensity. Also ν-value at the injection was varied in the range of 2.14 ~ 2.27, which was not useful to improve the beam intensity, and the beam intensity attained the maximum at the designed ν-value 2.25.

(3) Fine adjustment of the RF voltage envelope during acceleration period: this saved the loss during acceleration.

The extraction of beam from the booster is performed by a fast kicker (pulse-magnet) and a septum magnet. The extraction efficiency is about 100 %. The main ring is able to accomodate nine pulses of the booster beam in its circumference and the remaining pulses are switched by a pulse magnet into a new beam line leading them to the outside of the main ring and used for various researches such as neutron diffraction and radiobiology. (Booster beam utilization facility).

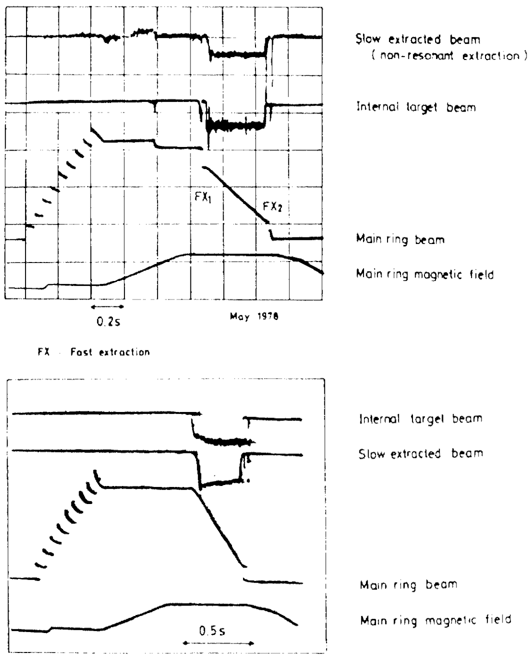
The main synchrtron is operated with a repetition cycle of approximately 0.5 Hz. Nine pulses from the booster are injected into the main ring during the injection period of 0.5 s. The acceleration is performed for the following 0.5 ~ 0.8 s depending on the maximum energy and 0.5 s flat top is used for high energy physics experiments. The magnetic field is 1.5 KG at the injection and 17.5 KG at 12 GeV.

The designed frequency of betatron oscillations is $\nu_x = \nu_y = 7.25$. However, it turned out after an extensive survey on tune diagram that the best operating point is $\nu_x = 7.12$ and $\nu_z = 6.18$ with correction of the octupole magnets.

The maximum beam intensity we have achieved so far is 2×10^{12} ppp at 12 GeV. Most significant improvement to increase the beam intensity was to eliminate the beam loss at the phase transition energy (5.4 GeV). A new gas monitor was installed to measure the radial deviation of the orbit, which is linked to the RF feedback system to suppress the beam oscillation before the transition and a new function generator was developed to control the beam orbit after the transition. One can notice a beam loss at the transition in the upper diagram of Fig. 4, which is improved in the lower diagram. Another improvement with the RF system was to have removed noises out of the RF phase-feedback loop. It was also helpful to correct the closed orbit distortion by a fine tuning of the steering magnet.

An effort is being devoted to improve the spill of the extracted beam. It is fairly flat so as to cause almost no problem for counter experiments using secondary particles. Nevertheless, sometimes there are some ripples in the extracted beam so that it may cause a trouble in counter experiments using the proton beam.

Fig. 4 Typical Pattern of Beam Sharing



Beam lines and beam sharing

Three beam lines are provided for physics experiments. The fast extracted beam is used for the KEK 1m bubble chamber. The internal target beam was the only beam available for counter experiments till early 1978. Now that the slow extracted beam and three beams from it are avilable, they are the main beams for counter experimetns. In order to reduce the residual radioactivity around the internal target, a thinner internal target is used at present so that the intensity of the internal target beam is limited to $\sim 10^{11}$ ppp.

Typical patterns of beam sharing are shown in Fig. 4, and the layout of counter experimental hall is illustrated in Fig. 5. The statistics of beam utilization is shown in Fig. 6, which indicates the rapid increase of the use of the slow extracted beam. Two kaon beam lines K2 and K3 have been completed recently. Their features are:

K2(Low momentum kaon beam) 1 ~ 2 GeV/c
K^+/K^- $10^6/5 \times 10^5$ at 2 GeV/c
π^+/π^- $6 \times 10^7/3 \times 10^7$

K3(Low momentum kaon beam) 0.5 ~ 1 GeV/c
K^+/K^- $10^5/2 \times 10^4$ at 0.8 GeV/c
π^+/π^- $5 \times 10^7/5 \times 10^7$

An example of mass separation in K2 line is demonstrated in Fig. 7.

Fig. 5 Layout of Counter Experimental Hall

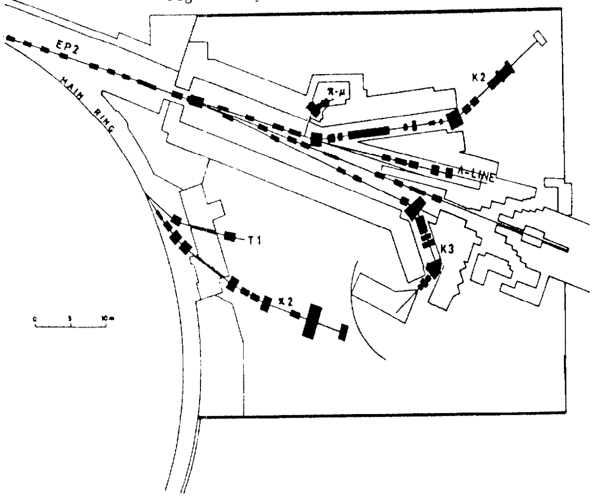


Fig. 7 Mass separation in K2 Beam line

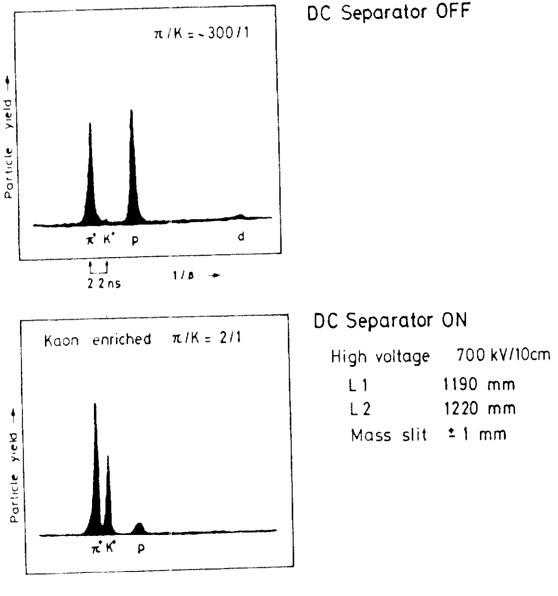
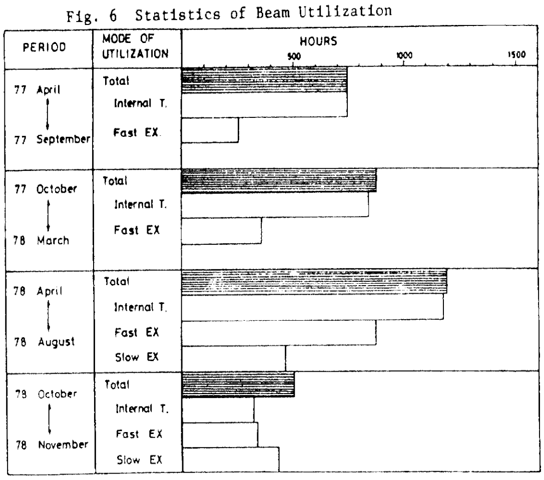


Fig. 6 Statistics of Beam Utilization



Booster beam utilization facility

As has been mentioned before, three quarters of the extracted 500 MeV protons can not be accepted by the main ring and is transported to the booster beam utilization facility, which affords three experimental areas, i.e., the neutron diffraction experiment area, the meson area and the medical research area.

A thick tungsten or uranium target will be used to produce neutrons. The estimated neutron yield for the incident proton intensity of 6×10^{11} ppp is as follows:

Neutron yield 20 neutrons/proton
fast neutron yield 1.2×10^{13} neutrons/pulse
fast neutron pulse width ~50 ns
slow neutron flux
 cold ($E < 5$ meV)
  10^{16} neutron/cm^2 s eV at $E = 2$ meV
 thermal (10 meV $< E <$ 200 meV, $\Delta t = 10 \sim 30$ μs)
  $1 \sim 2 \times 10^{15}$ neutrons/cm^2 s eV
 epithermal ($\Delta t < 3$ μs)
  0.5×10^{15} neutrons/cm^2 s eV at $E = 1$ eV

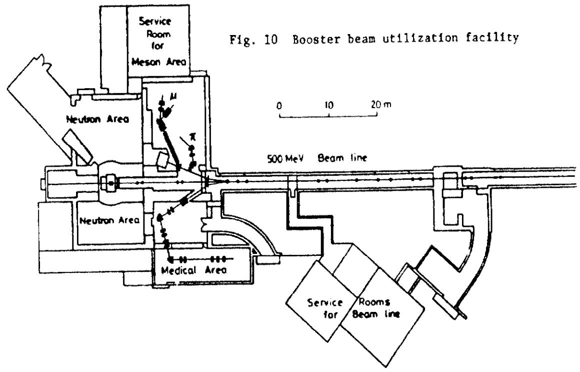
In the higher energy portion of the spectrum, the neutron flux is even larger than neutrons produced by powerful atomic reactors. A part of neutrons produced is used for medical treatment.

On the other hand, pion and muon flux is not so intense as those from so-called meson factories. Therefore, a superconducting magnet is going to be constructed in order to collect produced mesons as many as possible. The maximum muon intensity is estimated to be about 10^4/cm^2 s.

Diagnosis with protons is one of the main themes of medical researches, but the incident energy is too high for it and then a energy degrader (absorber) will be used to reduce the energy of protons below 200 MeV.

The overall layout of the booster beam utilization facility is shown in Fig. 10.

Fig. 10 Booster beam utilization facility



4. Photon Factory
(Synchrotron Radiation Research Facility)

Outline

The construction of "Photon Factory" for synchrotron radiation research was approved in the budget of Fy 1978 and now is making a steady progress as prearranged. According to the present schedule, it will be ready for users in 1982. Originally the "Photon Factory" project was planned to establish an independent institution. However it was found to be very difficult to prepare a site and staffs for its construction, and it was finally established as a part of KEK. The construction cost is about 1.65×10^{10} yen, of which 8.0×10^9 yen is for the accelerator complex and experimental facilities and 8.5×10^9 yen for buildings, the electric power station and the water cooling plant. The accelerator consists of a 2.5 GeV electron linac and an electron storage ring. In near future we will use this linac as an injector of electrons and positrons to the electron-proton colliding facility, "TRISTAN." Overall layout of the facility is shown in Fig. 8.

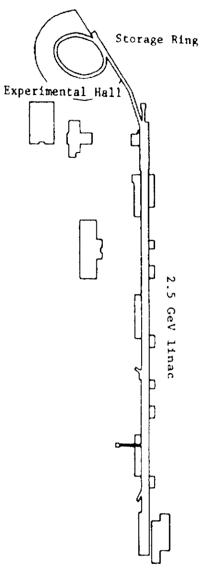


Fig. 8 Layout of Photon Factory

Electron linac

Now that this accelerator is a dedicated machine, special emphasis was laid on the easiness of operation and maintenance in the design principle. The conventional T-W type was adopted and the peak current was limited to 50 mA. In future expansion, a 200 MeV linac can be added as a positron source and also two storage rings, with energies 400 MeV and 1 GeV respectively, are under consideration. Principal parameters of the electron linac is given in Table 5.

Table 5. Parameters of electron linac

Maximum energy	2.5 GeV
Peak current	50 mA
Repetition rate	50 Hz
Beam width	1 μs
Average current	2.5 μA
Energy spread	±0.5 %
Type of acc. structure	TW, constant gradient
Operating frequency	2856 MHz
Length of acc. section	2 m
Number of acc. section	160
Total length	400 m
Klystron peak power	20 MW
Number of klystrons	40

Storage ring

The average diameter of the storage ring is about 187 m. The ring has the two-fold symmetry and is composed of 28 dipoles, 58 quadrupoles, 8 medium straight sections of 3.5 m in length and 2 long straight sections of 5 m in length. These straight sections are for the RF cavities, the injection septa and the wigglers. The parameters of the storage ring is given in Table 6.

Table 6. Parameters of the storage ring

Energy	2.5 GeV(max. 3 GeV)
Intensity	500 mA
Mean radius	29.77 m
Radius of curvature	8.66 m
Betatron number ν_x	6.25
ν_y	5.25
Bending magnet field	9.6 kG(max. 12 KG)
Length of bending magnet	1.85 m
Aperture	70×120 mm^2
Length of quadrupole magnet	0.5 m
RF frequency	500 MHz
Harmonic number	312
Synchrotron radiation loss	400 KeV/turn (w/o wiggler)
Radiated power	208 KW
RF voltage	2.1 MV
Synchronous phase	10°
Average pressure	10^{-9}
Expected lifetime	5 hr

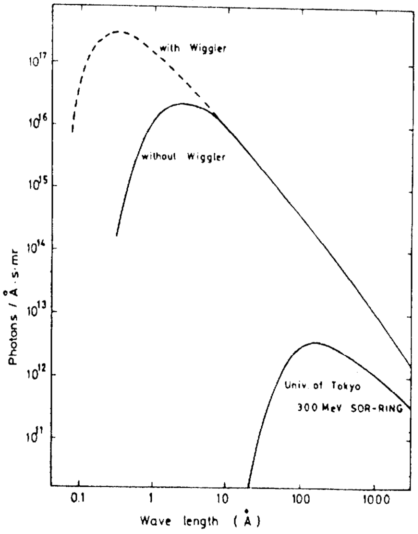
Synchrotron radiation

The experimental hall will be equipped with six beam lines, two for VUV and soft X-rays, three for X-rays which are produced by normal bending magnets. The last one is for hard X-rays produced by the wiggler magnet, which is a superconducting three poles magnet and wggles the electron beam in the vertical plane. The wiggler increases the radiation loss up to 470 KeV/turn. The expected properties of the stored beam and SOR are:

Energy spread of stored beam		$\pm 7.6 \times 10^{-4}$
Beam size	bunch length	5 ~ 10 cm
	radial	1.6 ~ 2.7 mm
	vertical	~0.5 mm
SOR Intensity		
	Bending magnet	2×10^6 photons/A·s·mr at 2.26 A
	Wiggler (60 KG)	6×10^{17} photons/A·s·mr at 0.38 A

The expected spectra are illustrated in Fig. 9, in comparison with SOR spectrum from the 300 MeV storage ring at University of Tokyo.

Fig. 9 SOR Spectrum



5. TRISTAN - Future Plan of KEK

The site of KEK is large enough to accomodate a larger ring with a circumference of more than 2 km. Therefore, it is a matter of course, as in other high energy projects, to make a future plan by the use of the present accelerator as an injector for the larger ring. The future plan of KEK, "TRISTAN", aims at high energy colliding beam experiments of various types such as pp, $e^{\pm}p$ and $e^{+}e^{-}$ by choosing a set of intersecting rings. Among these experiments, specific emphasis would be laid on an electron-proton colliding experiment since we are able to take advantage of 2.5 GeV electron linac as well as 12 GeV PS.

In the preliminary design of TRISTAN, which has been already reported at several occasions, the diameter of the large ring was taken to be six times (648 m) of that of 12 GeV main ring, and the maximum proton energy was about 200 GeV. However, taking account of the recent progress of elementary particle physics and of competing other projects, we have decided to scale up the original plan in order to raise the maximum energy up to 300 GeV. Three rings, i.e., two conventional rings and one superconducting ring, will be constructed in a same enclosure. Electrons and positrons are injected from 2.5 GeV linac into one of the conventional rings, Ring I, which accelerates and stores them. Ring II, which is also a conventional ring, plays a role of an intermediate accelerating ring for protons, by reason of the fact that 12 GeV is too low to be injected into the superconducting ring. The parameters of TRISTAN are given in Table 7, and the layout is shown in Fig. 11.

Table 7. TRISTAN Parameters

	Ring I	Ring II	Ring III
	conventional magnet		s.c. magnet
Particle	$e^{\pm}$	p	p
Circumference	$2638.9 \text{ m} = 2\pi \times 54 \text{ m} \times 7\frac{7}{9}$		
Average radius	420 m		
Average radius of curved section	324.5 m		
Straight Section	600 m = 150 m × 4		
Bending radius	222.5 m		
Energy	20 GeV	50~100 GeV	300 GeV
Bending Field	3 KG	7.5~15 KG	45 KG
Beam Current	0.2 A	1.2 A	14 A

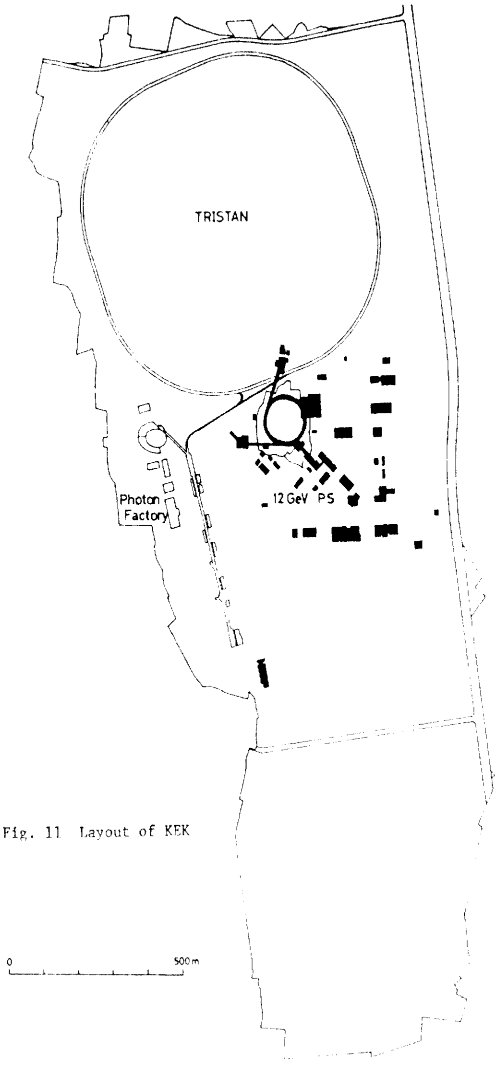


Fig. 11 Layout of KEK

References

(1) "Initial Operation of KEK 12 GeV Synchrotron" reported by T. Nishikawa at 1977 Particle Accelerator Conference. (Chicago)

(2) "KEK Status and Future Plan" reported by T. Kamei and T. Nishikawa at the International Conference on High Energy Accelerators, 1977. (Serpukov)