KEK STATUS AND FUTURE PLAN

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Introduction

After discussions extended over several years about the high energy physics project in Japan, the National Laboratory for High Energy Physics (KEK) was established in 1971. It is located in the Tsukuba academic city, about 70 km away from Tokyo. In order to get higher energy and higher intensity proton beams with the limited budget, a cascade type 8 GeV proton synchrotron was constructed. The main design parameters of the accelerator are shown in Table I and the layout is in Fig.1. The details of the design were already reported at the previous conference./1/

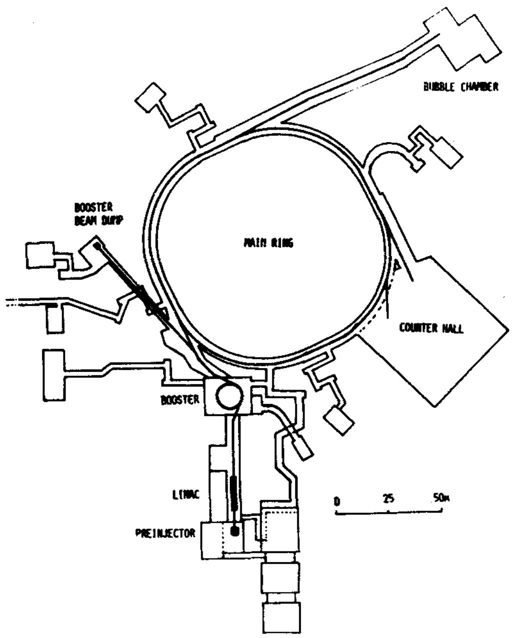

Fig.1 Layout of KEK Accelerator

Efforts of all accelerator staff have made good progress in the construction with various technical and engineering developments. Then in July 1974 the preinjector accelerated the first proton beam in Tsukuba to the designed energy 750 KeV. In August the linac

Table I. Parameters of KEK Accelerator

I. Main Ring

Kinetic Energy	12 GeV (8 GeV)
Intensity (Space Charge Limit)	$\geq 2\times10^{12}(1\times10^{13})$ppp
Type	Separated-Function
Focusing Order	FODO
Average Radius	54 m
Number of Superperiods	4
Number of Betatron Oscillations	7.25
Maximum Bending Field	17.5 kG
Injector Energy	0.5 GeV
Repetition Rate	0.5 Hz

II. Booster

Kinetic Energy	500 MeV
Intensity (Space Charge Limit)	6×10^{11} (3×10^{12})ppp
Type	Combined-Function
Focusing Order	FDFO
Average Radius	6.0 m
Number of Cells	8
Number of Betatron Oscillations	2.25
Maximum Magnetic Field	11 kG
Repetition Rate	20 Hz

III. Linac

Energy	20 MeV
Type	Single Tank D-T Linac
Cavity Length	15.5 m
Number of Cells	90
Peak Current	100 mA
Repetition Rate	20 Hz
Preinjector	750 kV Cockcroft-Walton

succeeded in acceleration of the beam to 20 MeV, and after fine adjustments of the performances by the preinjector and the linac groups, the beam of the linac was raised upto 50 mA in December of the same year. On the other hand, the booster group continued cautious adjustments of the booster synchrotron components and the first run for the injection test was planned on December 4, 1974. After tuning of the injection beam line, the booster accelerated the injected protons upto 450 MeV and an intensity of 10^{10} protons per pulse was attained with a little adjustment. One week later the booster enabled stable operations at the designed energy 500 MeV, and thus we got over one of the barriers in the cascade machine.

The most of the next year, 1975, was spent in the measurements and the alignments of the main ring magnets, the installations of the vacuum equipments, the test of the rf accelerating system and the injection system. In summer, the extraction from the booster was put into operation with a 100 % efficiency. The test run of the main synchrotron began in November and on the first day the full turn of the injected beam was observed. Following three months were devoted to tune various parts of the main ring system. On March 4, 1976, we could observe the beam signal extending to the top of the magnetic field beyond the transition energy. During the same month the maximum energy was raised upto 10 GeV and at the end of 1976 we succeeded in 11.8 GeV operation. The continuous operation over the designed energy 8 GeV will be possible after an increase of the magnet power supply system and the magnet cooling plant, and these will be finished this year.

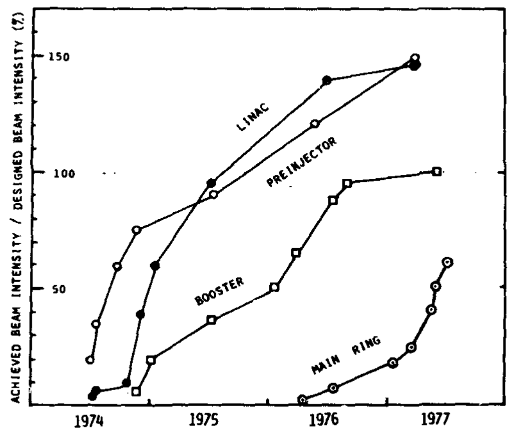

Fig.2 Achieved intensity via designed intensity (%) for each stage of KEK Accelerator.

The extensive machine study has being continued and the beam intensity for each stage of the accelerator has been increased as shown in Fig.2. The beams of the preinjector and the linac are 300 mA and 150 mA, respectively, and these are 50 % over the designed value and the booster intensity has already attained the designed value (6.0×10^{11} ppp). The maximum main ring intensity at 8 GeV is 1.2×10^{12} ppp with the nine booster beam pulse injection and exceeds a half of the designed intensity. The fast extraction to the bubble chamber beam line can be done with a 90 % efficiency and the internal target operation with the spill servo system produces the secondary particles for physics experiments. The beam sharing to the bubble chamber and the internal target during each main ring pulse has been successfully performed.

The whole accelerator system works with great reliability and stability, and about 90 % of the scheduled time have been used for the machine studies and the high energy experiments.

Operation Status

Preinjector

A proton beam from the modified duoplasmatron ion source is accelerated by the 750 kV Cockcroft-Walton generator. More than a 700 mA proton beam at the designed energy has been obtained with good stability by the improvements as follows.[2] One is shortening the accelerating gap from 22 cm to 18 cm and connecting the auto-bias between the plasma cup and the ion source anode. The other great improvement is reduction of sparkings as a result of increasing the column pressure to 2.5×10^{-4} Torr. This is ten times higher than the pressure of the ordinary one, and the sparking shows a marked decrease to less than one time per day. Then the preinjector is able to inject a 300 mA proton beam (∿15 μsec) to the linac cavity with a normalized emittance (90 %) of 3 ∿ 5 π mm·mrad. The beam transmission from the ion source to the cavity could be made better by a reconstruction of the matching section in the beam transport line, to adopt for the effect of gap shortening.

Linac

The 20 MeV linac has a single cavity of 15.5 m length with the prebuncher and the debuncher. The accelerating cavity fabricated by the electroplating process has very smooth surfaces and high mechanical precision, and its measured Q is more than 90 % of the calculated value.[3] This mirror-like surface of the cavity can reduce the rf conditioning time to one hour and sparkings are observed only several times during that period. The cavity is excited through the two feed points located at a quarter of the total length from the end plates and this feeding system is effective to suppress higher mode excitations. One MW of the rf power is enough to drive the cavity without a beam, and the beam loading compensation is required for a beam beyond 50 mA with 15 μsec width. Two power amplifiers can deliver 3 MW rf power to the cavity. The compensation is done by applying the pulse modulation voltage to the screen grid of the pre-driver tube. The achieved maximum beam current is 150 mA and for such heavy beam loading the amplitude modulation is not enough due to the cavity detuning. The linac operates nominally with a beam current of about 120 mA and the energy spread is ±1.2 % and ±0.3 % without and with the debuncher, respectively. The debuncher not only reduces the energy spread but stabilizes the mean energy, and the fluctuation of the mean energy becomes less than 0.15 %. The normalized emittance (90 %) at the same conditions is approximately 6 π mm·mrad.

Booster

The booster consists of eight combined-function magnets and a rf cavity, and its repetition is 20 Hz. The beam current of 80 mA transported from the linac is injected into the booster. The multi-turn injection scheme is used with two bump magnets and a septum magnet. The normalized horizontal acceptance is designed to be 50 π mm·mrad and several turn injection in the radial space is expected. The maximum current of a 500 mA beam circulates when the injection process is finished and the achieved number of the effective turns is about 6.[4] However, the transmission of the proton beam first captured by the injection system is about 30 %, and the major part of the loss occurs during one millisecond after the injection.[5] Then the obtained maximum intensity at 500 MeV is 6.0×10^{11} ppp that is the design value. A new rf cavity is being tested and the capture efficiency is expected to increase with an aid of this cavity.

In order to reduce the eddy current on vacuum tube by the fast changing magnetic field, a corrugated stainless tube 0.15 mm thick has been developed and its effective thickness is 0.03 mm. The vacuum system shows a trouble free performance.

The betatron frequency ν is chosen as 2.25 to raise the transition energy and actual ν is measured by an rf knock out method and the simple Q-meter.[6] The measured tune shift through the acceleration period is shown in Fig.3. The higher transition energy is desirable from the requirement for the tolerance of the magnetic field at the beam transfer to the main ring. The momentum spread of the extracted beam is estimated to be ±0.2 % and the fluctuation of the magnetic field of the booster at the transfer should be less than $\pm 4 \times 10^{-4}$. From considering the stability of the magnetic field and the accelerating frequency, the time duration ±100 μsec around the peak field can be available for the transfer. This time is too short to adjust the bunch phase to the rf bucket of the main ring due to the slow phase oscillation of the booster bunch and the phase matching is being performed as follows.[7] The booster acceleration frequency at the peak field is slightly shifted, for example 10 kHz, from the injection frequency of the main ring. Then the booster bunch slips with respect to the main ring rf bucket and the matching between these two is expected to occur during 100 μsec. When the phase matching is detected by the conventional fast logic circuit, the bunch is extracted by the fast kicker magnet. The extraction efficiency of about 100 % is obtained, and the horizontal and the vertical emittances of the extracted beam are about 40 π and 17 π mm·mrad, respectively, with a beam of 3×10^{11} ppp. In this case the horizontal emittance shows no blow-up in spite of the transverse coherent instability caused by the interaction between a bunch and a kicker magnet and the vertical one blows up without coherent instability in vertical direction.[8]

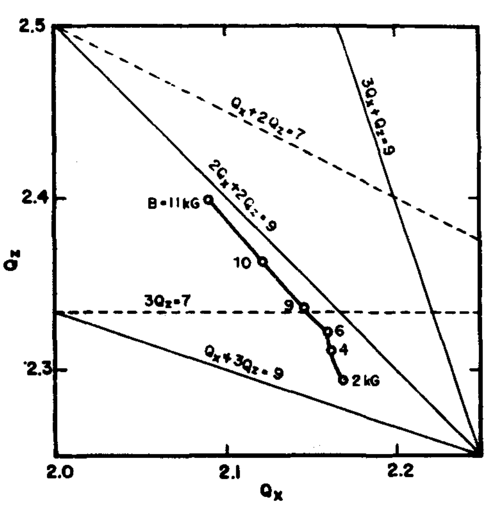

Fig.3 Working point in the tune diagram of the booster.

The main ring needs only nine booster pulses to fill its circumference in every main ring pulse (2.2 ∿ 2.5 sec), and the booster beam pulses between successive injections can be used for other purposes. The beam line guiding the booster beam outside the accelerator enclosure will be completed this summer and the extracted beam will be utilized for the pulsed neutron and the meson experiments.

Main Ring

The main ring has four superperiods, each containing seven unit cells, two of which have a missing magnet straight section. The extracted beam from the booster is injected into the main ring orbit with a septum magnet and a kicker magnet installed in a pair of the long straight sections. The other pairs of the long straight sections are used for three rf stations, the fast and the slow extractions. The injection is performed during 0.7 sec injection period. The acceleration to the maximum energy needs 0.5 $\sim$ 0.8 sec depending on the maximum field, and the 0.5 sec flat top can be used for the high energy experiments as shown in Fig.4.

With the use of the oriented low carbon steel, the C-type bending magnet can be operated up to about 17.3 kG and the maximum energy of the main ring has been successfully raised upto 11.8 GeV.

The bending and the quadrupole magnets are excited by the set of the thyristor controlled power supplies and these are operated in accordance with an inverter-converter combination mode. The currents are regulated by the computer and the tracking error between these two currents is less than 3×10^{-3}. For reducing the commercial line voltage flicker caused by the main ring magnet excitation, a thyristor reaction power compensator has been developed.[9]

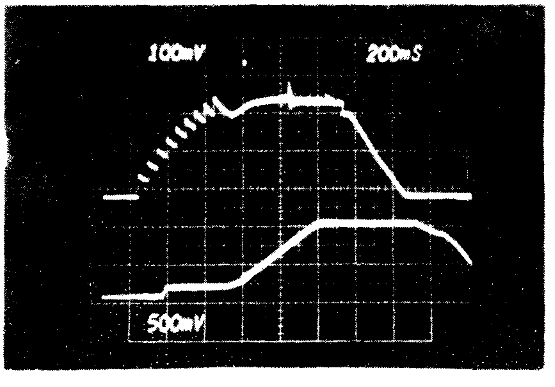

Fig.4 Acceleration of a main ring beam with nine booster pulse injection and beam sharing to the bubble chamber (fast extraction) and the internal target.

The closed orbit distortions of the injected beam are measured by the position electrodes distributed around the orbit, the fast position digitizer and the computer system,[10] and can be corrected by the steering dipole magnets within ±5 mm and ±2 mm in horizontal and vertical planes, respectively. The number of betatron oscillations is designed as $\nu_x = \nu_z = 7.25$. Untolerable chromaticity that is tune shift due to the momentum spread of the beam is corrected by the 16 sextupole magnets.[11] After the extensive studies for one year, the best operating point is $\nu_x = 7.12$, $\nu_z = 6.18$ with corrections of the octupole magnets. The intensity distribution in the (ν_x, ν_z) diagram during the d.c. field at 200 msec after the injection is shown in Fig.5. The injected beam continuously decreases during the d.c. field and comes down to the extent of 40 % at 0.5 sec after the injection. These beam losses would come partly from an injection error and from mismatchings of the injected beam to the longitudinal and transverse phase spaces of the main ring. An extensive survey of the aperture during the d.c. field, measurements of beam losses and residual activities have shown that the most beam losses occur in the vertical direction. An active beam damper is under construction in order to reduce the beam loss during the injection field.

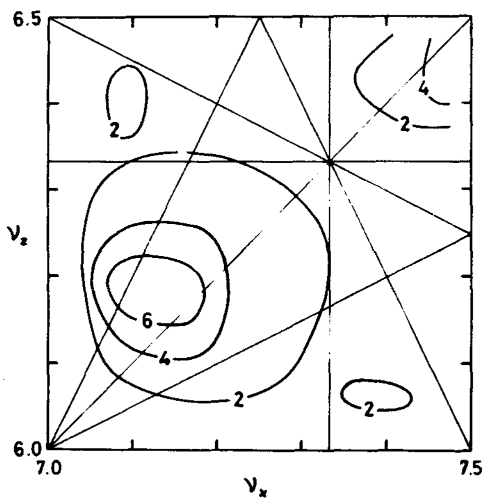

Fig.5 Intensity map in (ν_x, ν_z) diagram.

By careful adjustments of the booster and the injection to the main ring and by the improvements of the beam feedback control system, the maximum intensity of 1.2×10^{12} ppp with the nine booster pulse injection and 2×10^{11} ppp with the single pulse injection have been achieved. In these operations the intensity of the booster was about 3×10^{11} ppp. In case of the higher booster intensities ($>3 \times 10^{11}$ ppp) the beam emittances show blow-up in vertical direction, and the momentum spread of the extracted beam is not stable. The more precise studies of the main ring and the booster beams are being continued to accelerate more protons to the maximum energy.

Control and Vacuum System

The control system works well with assist of the computer network.[12] The data that are useful for the machine tuning are collected by the satellite computers and shown to the operator by the central system. Various types of the beam monitor including the non-destructive profile monitor have been developed.[13] Especially the one turn closed orbit display system that enables the measurement of the main ring orbit at a desired time after the injection is very useful for the orbit correction and the injection tuning.

The vacuum system with the ion pump and the sepcially developed metal gaskets show very reliable performances.[14] At the start of the main ring vacuum pumping, each ion pump works as the fore pump of the next one located at the nearest neighbor and stable operation is possible.

Beams for Physics Experiments

Accelerated beam to the falt top of the main ring magnet can be debunched by an rf frequency jump and disconnection of the phase-lock loop. A 400 msec debunched beam spill with the internal target can be obtained by a couple of the bump magnets with a spill servoloop. The fast extraction to the bubble chamber beam line is done by the beam sharing with the aid of an electrostatic septum and a septum magnet. The beam of several μsec width can be extracted with a high efficiency (>90 %) and with the emittances of $\varepsilon_H \approx \varepsilon_V \approx 5\ \pi$ mm·mr. The main ring beam can be shared into the bubble chamber beam line and the internal target during each flat top period as shown in Fig.4.

The slow extraction by a half-integer resonance will start after the device installations scheduled this fall.

The Future Plan

TRISTAN Plan

As stated, the future extension of the KEK proton synchrotron is taken into account even at the initiation of this project. "TRISTAN" (Transposal Ring Intersecting Storage Accelerators in Nippon) is a nickname of the future plan which aims at high-energy colliding beam experiments of various types such as pp, $e^{\pm}p$, e^+e^- and $p\bar{p}$ by choosing a set of intersecting rings.

The original TRISTAN[15] plan was composed of three rings installed in the same tunnel; two of them are superconducting and the remaining one is conventional. Now, however, considering financial and technical feasibilities we modified the original plan to divide it into Phase I and Phase II. In Phase I, two rings will be built; both conventional or one conventional and the other superconducting. Afterwards, further superconducting rings will be added at Phase II to achieve the final goal of the original plan.

The circumferences of these rings are about 2 km i.e. 6 or 7 times of the present main ring. Using two intersecting superconducting rings, one could obtain the maximum center-of-mass energy of about 400 GeV for the proton-proton colliding beam experiments. Before the protons extracted from the present main ring are stored and accelerated in the superconducting rings, they will be injected into a conventional ring and accelerated upto $\gtrsim$ 50 GeV. Thus the magnitude of magnetization and consequent a.c. losses in the superconducting rings will be reduced, and the transition energy will also be safely passed through during a fast acceleration in the conventional ring.

After the proton stacking in the superconducting rings, the conventional ring can be filled up with an electron beam giving a possibility of electron-proton colliding beam experiments. As an alternative, the conventional ring can also be used as an electron-positron colliding beam system at the maximum center-of-mass energy $\lesssim$ 35 GeV. In addition, the proton or electron beams accelerated by one of the composed rings could be extracted to the experimental halls for usual fixed target experiments.

After extensive studies among the high-energy physicists and accelerator scientists in this country, the first priority in Phase I of TRISTAN has been directed to the ep colliding beam experiments at the energy region where weak processes involving neutrino would become comparable to electromagnetic processes or large momentum-transfer strong interactions./16/

As for the electron injector, the 2.5 GeV electron linac of the "Photon Factory Project" will be used. The center-of-mass energy of $\sim$70 GeV and the maximum luminosity of 6×10^{31} cm^{-2}s^{-1} will be obtained for collisions of a 200 mA (electron or positron) beam of 16 GeV on a 14 A proton beam of 70 GeV./15/ The c.m. energy can be raised up to 110 GeV by using a superconducting ring which accelerates protons up to 200 GeV.

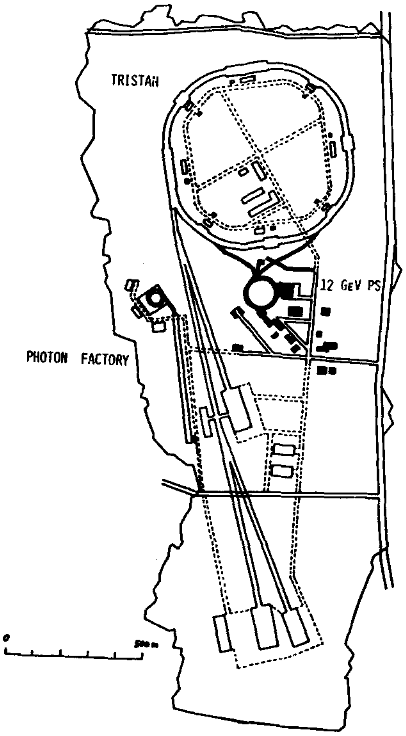

Fig.6 General layout of the 12 GeV PS "PHOTON FACTORY" and "TRISTAN".

Photon Factory Project

The Synchrotron radiation facility using a high-energy electron storage ring has drawn wide attention during these years. In KEK, the so-called "Photon Factory Project"/17/ has been under design to provide a new intense light sourse, which covers a wide range of wave length from ultraviolet to hard-X rays, dedicated to the scientific researches in various allied fields, such as pure and applied chemistry, biology and life science, medical applications, crystallography,mineralogy,solid-state physics,atomic and molecular science etc.

The project consists of a 2.5 GeV electron linac and an electron storage ring of the same energy. A stored current of more than 0.5 A is expected and, with a wiggler, the shortest wave-length of radiation may be extended to a 0.1 Å region. At least six beam ports will be prepared for the emerging lights; each designed for particular experimental programs.

The R & D money for this project has been authorized from this fiscal year and the project will start from the next year with a construction period of about 4 years. In cooperation with many possible user groups, the project team is working on the detailed design of the facilities.

The general layout of the present proton synchrotron, the "TRISTAN Plan", and the "Photon Factory Project" in the KEK Laboratory site is shown in Fig.6. The total laboratory site contains approximately 220 hα.

Acknowledgment

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ДИСКУССИЯ

<u>R.Martin:</u> Do you have any plans for accelerating polarized protons in the KEK machine?

<u>Dr.Kamei:</u> At present we have no plan. However, the ways to accelerate polarized protons in the booster ($Q = 2.25$) are being considered. (A Lamb-shift type polarized H^- source has been developed. Beams of more than 1 μA are achieved with the polarization of 70% in pulse operation.)