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INITIAL OPERATION OF KEK ACCELERATOR

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Summary

A brief description is given about the initial operation of the KEK Accelerator, which has yielded its design specification since a year ago. Through extensive machine studies, the accelerator achieved a peak energy of 12 GeV and a peak intensity more than 5×10^{11} ppp. Some related problems we met are discussed with the distinct features of the accelerator construction.

Introduction

It passed more than fifteen years after the Japanese scientists started a discussion on the construction of a proton synchrotron over ten Gev. At that time, only a small number of scientists existed in Japan who have some experiences on modern accelerator arts. In 1965, a research and development money ($\sim 10^8$ yen) was included in the National Budget to study the possibility of materialization of accelerator plan. A study group on the accelerator plan first headed by Professor H. Kumagai and successively by Professor S. Suwa was organized in the Institute for Nuclear Study, University of Tokyo. However, we had wasted 5 years with discussions on the type of the machine, effects on and relation to the researches in other fields of science, and the organization problems of establishing a new laboratory for this purpose. As a result, an original plan of a conventional 40 GeV proton synchrotron had been proposed with a total budget of about 3×10^{10} yen including cosmic-ray and other research facilities for elementary particle physics. In a general opinion, however, the whole project seemd to be so enormous that it took tedious discussions in many committees, and even that it became a political dispute. After a great effort of determined people, the establishment of the National Laboratory for High Energy Physics (KEK) was authorized by our scientific authorities in 1970. However, the total budget had been reduced to one quarter of the original plan, with the proviso in relevant reports that the authorized plan leaves the possibility of future extension. In this respect, an entire site alloted to the KEK comprises approximately 500 acres in Tsukuba, 45 miles north-east of Tokyo where the Japanese Government has been constructing a new academic town dedicated to scientific research and education.

As a principal instrument of the KEK, the accelerator plan was entirely reexamined by my active and competent colleagues, and design feature of the present PS was decided early 1971. The construction of the accelerator parts and their enclosures started in the same year by united efforts of the laboratory staff and the industrial company engineers including many engineering and technical developments.[1] In July '74, the preinjector demonstrated the first accelerated proton beam in Tsukuba with a 100 mA beam current and design energy. Then followed the successful operations of the linac on August 1. After several months of effort for polishing the performance of components, our linac group succeeded in providing a proton beam of approximately 50 mA at 20 MeV toward the booster. Meanwhile, another group put together the booster complex and a run on December 4, '74, was scheduled mainly to tune the beam-line from the linac to the booster. But, the tuning went so smoothly that only four hours later the injection system was brought into action and about 110 turns of circulating protons were observed. Immediately, we switched the r.f. acceleration system and the intensity monitor recorded the pulse spanned out to 15 ms which corresponds to protons surviving to an energy of 250 MeV. During the same night, the booster yielded its 450 MeV proton beam by a further adjustment with an intensity of 10^{10} protons per pulse. A week later, the booster group succeeded in managing to deliver its proton beam onto the design energy of 500 MeV.

The next year, 1975, was mostly devoted to installations of the bending and Q-magnets, r.f. accelerating system, vacuum equipments, and other necessary components in the main-ring enclosure. The extraction and injection systems from the booster to the main-ring came into proper action with a 100 % extraction efficiency. The central control system and the main-ring power supplies were almost complete. On November 21, the first attempt was made to inject protons into the main-ring and in the midnight the first full turn around the main-ring was demonstrated. During two to three months, however, we had fought with protons in our main-ring to accelerate them upto the design energy. Taking steps from 500 MeV to 2 GeV, 4 GeV, and 5.4 GeV (the transition energy), the early morning of March 4,'76, we finally observed in our beam monitoring system that protons went all the way to 8 GeV in pretty stable manner. About 4 years ago from the best day for us, we promised our future users that we shall obtain this energy by the end of Fy '75, i.e. March 31st of '76. We were a little proud of our accelerator since the top energy soon reached to 10 GeV.

Then, our small accelerator group (only 80 people in total even at the final stage of the construction) has backed from the record-making efforts to the daily work to improve the beam intensity in every stages of the accelerator and make the operation stable and reliable. Extensive machine studies had shown during the last year that the linac can accelerate 150 mA peak current with a 15 μs pulse width and the booster 5.7×10^{11} protons per pulse upto the design energy. These intensities are approximately or more than the design values. Then, much attention has been paid to the main-ring tuning so as to increase the trapping efficiency of protons injected from the booster, and to reduce the losses of the circulating beam particularly at the injection, acceleration start and transition.

Meantime, the computer control system of the main-ring power supplies was improved and became capable of compensating the saturation effect. On December 22 of the last year, the magnet power supplies were set to take the field corresponding to 11.8 GeV. Only a few minutes later we observed the protons injected with this magnet cycle resulted in acceleration right up to the top energy.

The main design parameters of the KEK Accelerator are given in Table I. So far, the accelerator testing has shown that, with the exception of peak beam intensity of the main-ring which has been about a quarter of the design value, almost all specifications have been met or bettered. The operation is quite reliable so that about 80 % of the scheduled machine time was performed from the initial test operation. The total cost used for the accelerator completion is approximately 5×10^9 yen and also comfortably within the initial estimate taking the inflation factor of these years into account.

The protons accelerated in the main-ring can already be shared into the fast-extracted beam toward the bubble chamber beam line and the internal target to produce secondary particles at the counter experimental hall. The scheduled experimental program will be under way from early May of this year and soon Japanese physicists will have the first opportunity to join themselves in the world high-energy physics field with their own proton facilities.

Operation Status of Each Stage of KEK Accelerator

An aerial view of the KEK Accelerator Complex is shown in Fig.1. The whole accelerator takes a four-stage accelerating system: the 750 keV Cockcroft-Walton Preinjector, the 20 MeV Linac, the 500 MeV Fast-cycling Booster and the 12 GeV Main-Ring. In the followings, we shall briefly give an up-to-date description of the operation status of each stage of the accelerator.

Preinjector

An operation report on the preinjector with the ion source has been given at the 1976 Proton Linac Conference at Chalk River, Canada, by S. Fukumoto and his group so that only a few words will be given here.[2] The original ion-source used was the modified duoplasmatron with a nozzle-type expansion cup. It was able to provide a 300 mA proton beam with a small emittance resulting in a large brightness. However, for a higher current, the beam showed an intensity modulation within the pulse duration (15 μs) probably due to a plasma instability. It was shown that such a modulation can be removed by applying a negative bias voltage to the plasma cup. Nowadays, in order to get more than 500 mA of beam current, the original plasma cup was removed and the extractor has been connected to the source anode by a 1 kΩ auto-bias resistor.

A couple of large accelerating columns which are not stacks of insulator rings and metal plates, is used for increasing mechanical strength and protecting the column against earthquake vibrations. In routine, a proton beam of approximately 700 mA is obtained at 750 keV. Passing through a beam line of 7 meters in length including beam slits, a beam schutter and a beam prebunching system, a beam current more than 300 mA can be obtained at the linac entrance with a normalized emittance of 0.3 ∿ 0.5 πcm mrad.

Linac

The linac group headed by J. Tanaka has also presented an operation report at the Chalk River Conference.[3] As is emphasized in the report, the development and usage of an electroplating method of the copper onto the steel have shown a great advantage to reliable and stable operation of the Linac. The smooth and clean mirror surfaces obtained make easy the r.f. high power excitation and the evacuation of the cavity. The high accuracy in machining process also ensures the theoretically expected field distribution and the design performance of the linac without any special or complicated tuning procedures.

The single-cavity structure of 16 m in its total length is fed the r.f. power from two points; each a quarter of the total length apart from the each end of the cavity. This double-feeding system suppresses higher-mode excitations and enables us to compensate beam loading evenly. With the aid of successful operations of the beam-prebunching, transverse focusing and beam-loading compensation systems, so far the maximum beam current of 150 mA was obtained. At 20 MeV, the energy spread of a 120 mA proton beam is less than ±1 % without the debuncher and ± 0.3 % with the debuncher. The normalized emittance at the same condition is approximately 0.6 πcm mrad, or no remarkable emittance grow-up is observed during acceleration.

Booster

After passing through the beam line of 38 m long incorporating 20 quadrupoles, 8 steering magnets, and a couple of pulsed bending magnets, the proton beam from the linac arrives at the injection porch of the booster. Although, such a long distance is left for future extention of the linac, more than 80 % of the linac beam can be transported with the normalized emittance of ∿ πcm mrad that is quite acceptable to the booster.

The booster is a fast-cycling proton synchrotron with the repetition frequnecy of 20 Hz corresponding to the resonant excitation frequency of the magnet system. The design aim of using the booster in our accelerator is on raising the beam intensity in the main-ring. The booster has an average diameter of 12 m which is one-ninth of the main-ring diameter, so that nine pulses of the booster are injected into the main-ring to fill-up its total circumference. A view of the booster synchrotron is given in Fig.2.

We ourselves were with astonishment when the booster accelerated protons almost to its design energy even in the first night scheduled to the beam-line tuning and the test of the injection system. Because a number of technical probelms were foreseen to be solved in such a fast-cycling proton synchrotron at low energies. They are large and rapid modulations both in frequency and amplitude of r.f. accelerating system, severe tolerance requirements to the magnetic field distribution, fast and proper control of proton motions during the injection and acceleration period and so on. After the initial success, the booster group really had frustrating months to increase the beam intensity and to make the beam stable and reliable. As a result, the maximum beam intensity so far we obtained is 5.7×10^{11} ppp at 500 MeV which is very close to the design intensity of 6×10^{11} ppp. In accordance with the improvement of linac performance, the maximum circulating current of approximately 500 mA has been obtained at the moment of 20 μs after the injection process started. This value of the beam current corresponds to 1.9×10^{12} ppp or the number of effective turns of multi-turn injection comes up about 6.7. At present, however, the transmission of the proton beam first captured by the injection system is about 30 %. The most beam losses take place during one millisecond after injection, so that the trapping efficiency is presumably determined by the injection process and may be affected by the beam intensity. The efficiency could be improved by installation of a new r.f. cavity which, in cooperation with the present one, will increase the maximum r.f. accelerating voltage and also flexibility of the r.f. system. A report on the booster r.f. system is given at this Conference by M. Kondoh and his colleagues.[4]

The performance of the system extracting the beam from the booster toward the main-ring has measured up to design expectations, and extraction efficiency of 100 % within an error of 5 % is obtained. The horizontal and vertical emittances of the extracted beam are 5 and 1.5 πcm mrad, respectively, and are quite close to the design values. It is required from the synchronization process of the beam transfer from the booster to the main-ring that the pulse-to-pulse fluctuation of the maximum momentum of protons should be within a limit of 4×10^{-4}. The requirement seems to be satisfied both for the magnetic field and the r.f. accelerating frequency at lower intensities. At higher intensities ($\gtrsim 3 \times 10^{11}$ ppp), however, effect of coherent beam instability corrupts the stability in some cases (Fig.3).

The stability has been under investigation, and it is partly caused by a kicker-magnet to beam interactions.

Finally, it is noted that only nine pulses of the booster beam extracted are injected into the main-ring for every 2 seconds, so that about three-quarter of the total pulses are remained and will be used for other applications as pulsed neutron experiments, π-μ physics experiments, and medical or biological applications. For these purposes, a new beam line switched out from the way to the main-ring is now under construction. The line will deliver the booster beam into an experimental hall outside the accelerator enclosure.

Detailed descriptions of the booster system have also been reported in other places and are summarized by H. Sasaki in a separate report contributed to this Conference.[5]

Main-Ring

The main-ring has four superperiods, each containing seven unit cells, two of which have a missing-magnet straight section of 5.5 m long. For flexibility, a separated-function type FODO lattice is employed. Each straight section is used for injection, fast extraction to the bubble chamber, slow extraction to the counter hall, and r.f. acceleration, respectively. The nine pulses from the booster are injected into the main-ring within 0.5 s while the main-ring guide field is held constant at 1.5 kG. The acceleration takes place in the following 0.8 s (0.5 ∿ 0.7s) and a 12 GeV (8 GeV) proton beam can be obtained at the guide field of 17.6 kG (12.1 kG). A flat top of $\lesssim$ 0.5 s at the peak energy is reserved for extracting protons into the experimental hall.

The main-ring enclosure and most of the auxiliary or the service buildings were completed in 1973. All of 48 bending and 56 quadrupole magnets were installed and set with an average error of 0.1 mm or less in Fy '74 (Fig.4). The main-ring magnet power supplies were also manufactured in Fy '73 and '74, and then brought into action in the service building. Meanwhile, all other components necessary for the main-ring operation such as the r.f. accelerating system, the beam-transfer and injection system, the control and beam-monitoring system and the vacuum system were installed.

After extensive field measurements of each magnet and investigations of every other components, the whole machine was brought together, and then, on November 21, '75, the first attempt was made to test it with real protons from the booster. We started the testing to inject protons into the main-ring and to hold them circulating full turns around the ring. This first attempt led to a successful result in the midnight of that day scheduled. The booster provided 2×10^{11} protons per pulse and approximately a half of them survived circulating more than 100 turns around the main-ring. Subsequently, we took a few steps forwards, and then met some difficulties in accelerating protons to the design energy. Before Christmas and New Year holidays we maneuvered to accelerate protons to an energy of about 4 GeV but in aukward manner. At the beginning of the last year, a trouble in interlock system of the beam line from the preinjector to the linac caused a burnout accident in the magnet system resulting in a three-week shutdown. On February 28, after a thorough study on the beam control via r.f. accelerating system, examination of the Q diagram and vertical and horizontal aperture survey, the beam was accelerated upto 5.4 GeV, just around the transition energy, and then lost there. It had been clarified at that time that main difficulties came from the low-level r.f. system, so that the beam monitor, phase-lock and position feedback systems were improved. The operation point in the Q-diagram was adjusted together with the sextupole corrections for removing the chromaticity. It was also necessary to reduce the tracking error between the guiding and focusing fields within 0.3 %.

The long-awaited day arrived on March 4, '76, when the beam sailed out beyond the transition energy and reached to 8 GeV in a pretty stable beam (Fig.5). The intensity was estimated at 2×10^{10} ppp, or the trapping efficiency ($\gtrsim$ 10 %) increased about one-order as compared with the value at the end of '75. Two weeks later, the first attempt was also made to inject nine pulses from the booster into the main-ring leading to a beam intensity of 8×10^{10} ppp.

It is notified here that we have used C-type bending magnets for our main-ring considering its better accessibility which makes beam handling and maintenance easier. Thus a maximum field of about 13 kG or a corresponding peak energy of about 8 GeV would be expected, if we had used conventional magnetic materials for the magnets. As an alternative, in collaboration with Japanese steel and electric companies, our magnet group developed and used oriented low carbon steels (lamination thickness of 1 mm) both for the bending and quadrupole magnets.[6] As a result, we thought that a peak guide field of approximately 18 kG could be obtained. On March 19, '76, we attempted to set the magnet power supplies to take the field up beyond the level corresponding to 8 GeV and succeeded in accelerating protons upto 10.4 GeV. However, a saturation effect of the magnet system causes a breaker trouble in the AC filter line of the power supplies and the first test-operation was brought to an end. Another success came eight months later or the year-end after the power supplies and their control system had been improved by the power supply group headed by M. Masuda to provide a sufficient current for a 12 GeV operation under a digital and analog hybrid control program.[7] An 11.8 GeV beam corresponding to the field level of 17.3 kG was obtained with the beam intensity of about 3×10^{10} ppp.

It also took us about a year to perform machine study primarily aimed at increasing the beam intensity. The beam intensity gradually increased, and so far the maximum intensity of 1.1×10^{11} ppp with the single-pulse injection and 5.4×10^{11} ppp with the nine pulse injection from the booster were obtained. With the single-pulse operation, about a 10 % of the injected beam is lost during the first 100 μs and another 20 % during 1 ms. These beam losses will come partly from an injection error and from mismatchings of the injected beam to the longitudinal and transverse phase spaces of the main-ring. The beam intensity also continuously decreases during the d.c. field operation at the injection energy and comes down to the extent of 30 % at 0.5 s after injection. During acceleration, protons are scarcely lost, except a period at the acceleration start and at the transition energy when the control via r.f. system or magnet power supply was incorrectly adjusted. Thus in the case of the nine-pulse injection, trapping efficiencies spread out from pulse to pulse as some 30 % to 50 % (Fig.6).

A series of the extensive survey of the beam size and the vertical aperture showed that most beam losses occur in vertical direction. In this respect, we had an experience after a long shunt down to take out the booster beam-dump outside the accelerator enclosure for the purpose of pulsed neutron experiments and other applications. At the same time, the beam channels to the bubble chamber and counter experimental halls were installed together with a shielding construction. Due to these construction works, we observed long-term ground motions which caused misalignment of the magnet system of 2 ∿ 3 mm around the ring. Since the position errors of quadrupole magnets should be less than 0.1 mm, we couldn't cancel out the errors by a set of trim magnets. After a quick correction of the alignment of the Q-magnet system, we obtained about a twice of the beam intensity before the correction. A coupling between horizontal and vertical motions was also observed at the initial stage of the machine study, and partly suppressed by a set of skew quadrupoles. So far, the operating point in the Q-diagram had mostly been set at $\nu_x = 7.12$ and $\nu_z = 7.21$, but recently it was found that the choice of a set at $\nu_x \approx 7.10$ and $\nu_z \approx 6.20$ looks favorable to get a higher intensity without the coupling effect.

The momentum spread of the beam extracted from the booster has about 0.5 $\sim$ 0.6 % corresponding to the r.f. voltage at the final stage of the booster acceleration. This would cause the longitudinal mismatching to the r.f. bucket formed by the main-ring r.f. system. Such a mismatching would result in a filamentation inside the bucket and produce the losses in radial direction through the $X_p - \frac{\Delta p}{p}$ coupling. We expect the mismatching could be eliminated by the improvement of the r.f. system in the booster so as to reduce the momentum spread at its top energy.

At this Conference, separate reports both on the beam transfer system from the booster to the main-ring and on the beam life time in the main-ring are given by Y. Kimura and his group and by M. Kihara and his colleagues, respectively.[8,9]

Status of Other Subsystems of KEK Accelerator

Beam Extraction Systems and Beam Channels for Physics Experiments

The internal target and associated beam channel system have also been tested from the end of the last year. We have used a target of 1 mm in diameter and 2 cm in length; it is made of aluminum and set in 10 degree to the azimuthal direction so as to make a multi-traversal interaction. By using a couple of bump magnets, we can spill the circulating beam for a duration of 400 ms (Fig.7). It is also possible to debunch the beam at the flat top by switching off the gate circuit for the phase-lock system and then by introducing an r.f. frequency jump. Depending upon timing of the gate-off, the momentum spread is chosen as we like, through a decoupling process between the r.f. system and proton motions. The pion flux obtained is 1.3×10^9 π^+/GeV/c./str./pulse at the momentum of 4 GeV/c.

The circulating beam could also be shared into the bubbel chamber beam-line and the internal target channels. The fast extraction system from the main-ring to the bubble chamber (1 m in its diameter) consists of an electrostatic septum and a fast kicker magnet, leading to a few μs beam width with emittances of $\varepsilon_H \approx \varepsilon_V \approx$ 0.5 πcm mr. The horizontal emittance is observed to be reduced to about 1/3 of that in the main-ring by beam shaving at the electrostatic septum. The maximum efficiency of about 92 % is achieved for the full extraction of the 8 GeV beam. Together with the beam-line tuning, the first attempt was made to take a bubble chamber picture at the end of the last February.

Although counter experiments will start by using the internal target channels, a slow extraction system using a half-integer resonance has been designed, and its necessary equipments as septum and bump magnets have been almost complete. It is also necessary to improve the power supplies to give a stable flat-top operation with a fluctuation less than 10^{-5}. Subsequently, the whole slow extraction system with the secondary beam lines for kaon experiments will be brought into action by the end of this year.

Beam Monitoring and Control System

A number of beam monitors are used to pursue proton beams everywhere along the accelerator: they are slow and fast intensity monitors, beam position monitors, destructive and non-destructive beam profile monitors, emittance measuring equipments and other special purpose monitoring systems. Most of informations obtained by these monitoring equipments are displayed on screens of various types, commercially available or home-made scopes. A typical picture obtained by a non-destructive beam profile monitor using ionization of residual gases is shown in Fig.8, demonstrating the beam circulating all the way to 12 GeV.[10]

The final goal of the machine operation is to be capable of entire machine control from a single console in the central control room. At present, however, several local control stations assist the machine operation from their own consoles. In particular, the main-ring power supply has its own computer control system for independent operation of the power system.

The central control system involves a network computer system consisting of seven Melcom-70 type computers. The main computer communicates with the operator, stores and prints out the data collected from satellite computers, produces displays of accelerator parameters and develops various application programs. One of the satellite computers assists data-collection at the control room and other five collect data from or send commands to the distinct parts of the accelerator including experimental beam lines.

Both the beam monitoring and computer control systems have been helpful to perform machine study easily and effectively; the details are referred to papers contributed to this Conference by our Control and Monitor group headed by T. Kamei.[11]

Vacuum System

Since we aim at a high intensity and reliable operation throughout the whole accelerator complex, much attention has been given to the vacuum system. To protect the vacuum equipments against radiation damage, we have made an effort to avoid any organic element from the vacuum system. For this purpose, G. Horikoshi and his colleagues have developed a new type of metal gasket called "H-type gasket".[12] The H-type gasket works well at a compressive force of less than 7 kg/mm or within elastic deformation region, so that it can be used many times repeatedly. Taking this advantage, they also developed an all metallic gate-valve which is useful for our vacuum system.

The booster is a fast-cycling synchrotron and the eddy currents induced on the vacuum envelope would cause a significant error in magnetic field distribution. In order to reduce this effect, our vacuum group developed a corrugated stainless tube, whose effective thickness is 0.03 mm. It is, however, not yet clear whether this type of vacuum envelope is responsible to the beam instability caused at a high intensity operation of the booster.

The control and interlock philosophy of the vacuum equipments distributed around the main-ring has advanced a distinct method, in which an ion pump attached to one position of the vacuum doughnut acts as the fore pump of the next one located at its nearest neighbor, successively. So far, we have had no serious trouble in the main ring vacuum system. Investigation on the vacuum instability due to an increasing gas pressure has also been done during the machine study.

Operation Results and Remarks

Table II gives some of the more significant events and dates. Table III is a list of operation hours with an analysis of the down times. Fig. 9 shows the intensity-year curve for each stage of the accelerator; the value obtained is normalized to the design intensity.

Our operation crew is directed by Y. Kojima and has responsibility to keep each run stable, reliable and in safety. To keep safety, the operation crew collaborates with the Radiation and Safety Control Division of the Laboratory and always monitors the indication of radiation detectors distributed in the buildings and laboratory sites. A key-safety system is also used for protecting any person from the radiation area while the machine running.

As stated above, the KEK Accelerator is the high-energy proton facility first built in Japan. The experiments utilizing the accelerator are to be carried out not only by the KEK physics group but also by the scientists from other universities and institutions as the common-use national accelerator.

The first users for the scheduled experiments are the teams from the Kyoto and Nagoya University in the field of counter experiments and the team from the Tokyo Metropolitan University and the KEK own group at the bubble chamber. The accelerator will also be used for researches in the inter-discipline fields as the utilization of the booster beam. In addition, it shoud be noted that international collaborations in the field of accelerator science and high-energy physics have arised in Japan from the initial stage of the accelerator construction.

Finally, the author would like to express his sincere thanks to many people supported our project in various aspects of the machine construction. He is also grateful for collaboration with Professors S. Suwa, K. Kikuchi and all other colleagues in the KEK Laboratory.

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Table I. Parameters of KEK Accelerator

I. Main Ring	
Kinetic Energy	12 GeV (8 GeV)
Intensity (Space Charge Limit)	$\geq 2\times10^{12}$ (1×10^{13})ppp
Type	Separated-Function
Focusing Order	FODO
Average Radius	54 m
Number of Superperiod	4
Number of Betatron Oscillations	7.25
Maximum Bending Field	17.5 kG
Injection 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

Table II. Significant Events and Dates of KEK Accelerator Construction

April '71	Construction Started.
July 23,'74	First Beam of Preinjector (100 mA)
Aug. 1,'74	First Beam of Linac (4 mA)
Dec. 4,'74	First Beam of Booster (450 MeV, 9×10^{9} ppp)
Dec. 12,'74	500 MeV in Booster (4×10^{10} ppp)
Nov. 19,'75	First Full Turns in Main Ring
Mar. 4,'76	8 GeV in Main-Ring (2×10^{10} ppp)
Mar. 19,'76	10.4 GeV in Main-Ring (4×10^{9} ppp)
Nov. 10,'76	Linac Intensity: 150 mA, 15 μs Pulse Width
Nov. 12,'76	Booster Intensity: 5.7×10^{11} ppp
Dec. 19,'76	11.8 GeV in Main-Ring (3×10^{10} ppp)
Feb. 23,'77	Main-Ring Intensity: 5.4×10^{11} ppp

Table III. Total Operation Hours and Down Times of KEK Accelerator

	Nov.'75∿ Mar.'76	June'76∿ Aug.'76	Nov.'76∿ Mar.'77
Total Ope. Hours	521.3	477.9	1000.6
Down Times (% of Total Operation Hours)			
Preinjector	0.65	0.19	0.73
Linac	2.21	1.61	2.34
B. Magnet	1.21	0.65	0.14
B. RF	4.11	0.52	1.25
Beam Transport	1.15	2.57	1.59
MR. Magnet	0.06	0.04	0.03
MR. Power Supply	1.27	1.55	0.07
MR. RF	0.67	0.02	1.16
Vacuum	0.08	0.04	0.11
Controls	1.40	0.08	0.16
Utilities	0.35	0.00	0.02
Human Error	not counted	0.13	0.11

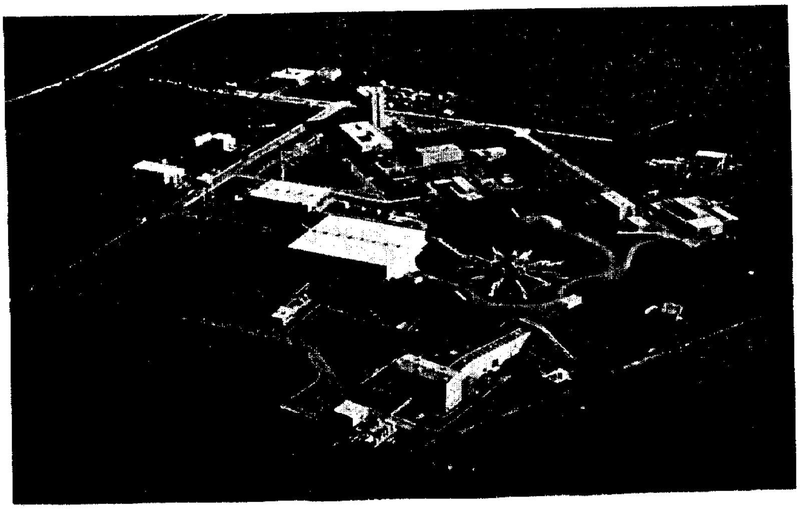

Fig.1 Aerial view of KEK

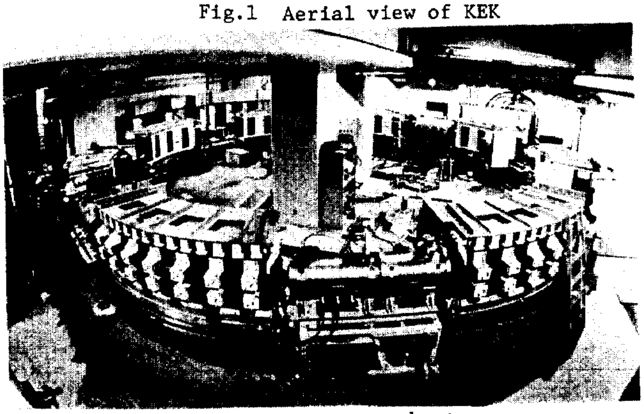

Fig.2 Booster synchrotron

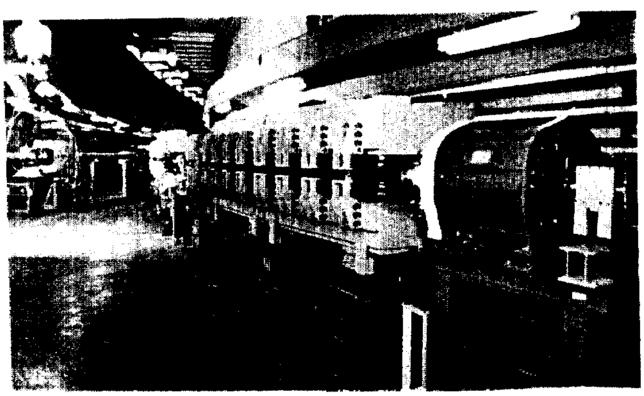

Fig.4 Main-ring tunnel

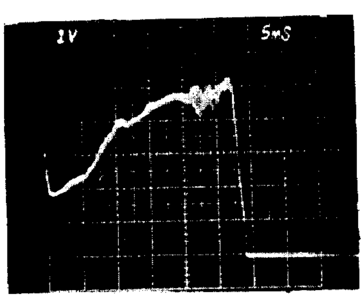

Fig.3 Signal of a booster beam showing a coherent instability near peak energy (Intensity: 5.2×10^{11} ppp)

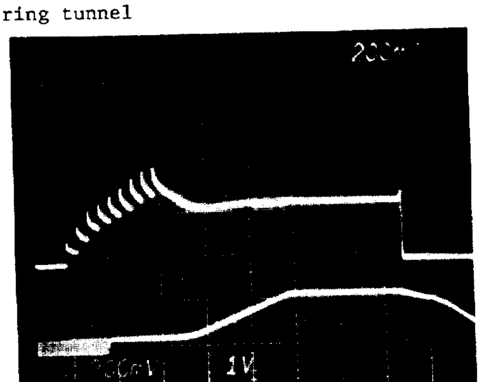

Fig.6 Beam signal in the main-ring when nine pulses of the booster are injected (Intensity: 5×10^{11} ppp)

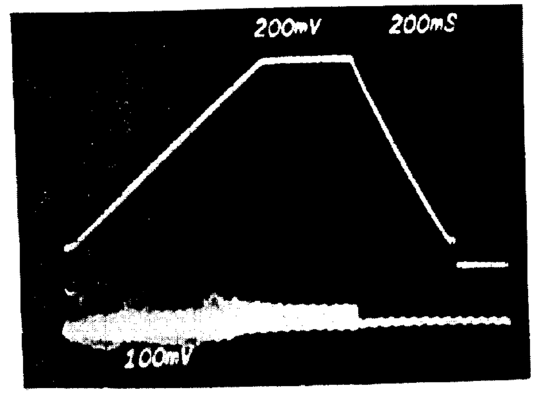

Fig.5 Signal of the first 8 GeV beam with the magnetic field pattern

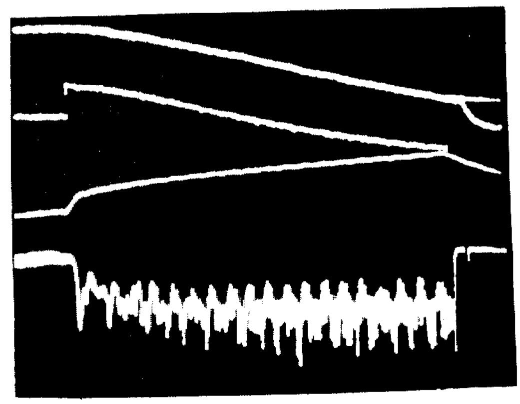

Fig.7 Spill of the beam onto the internal target (trace IV). Trace I: intensity in the main ring, trace II: bump magnet current for the servo control of the spill, trace III: main bump magnet current.

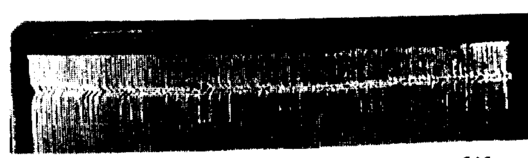

Fig.8 Signal of a nondestructive profile monitor at the main-ring (0.5 GeV to 12 GeV)

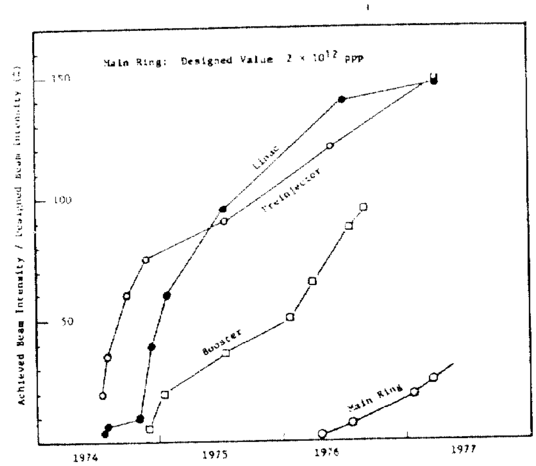

Fig.9 Achieved intensity via design intensity (%) for each stage of KEK Accelerator.