AN OVERVIEW OF ACCELERATOR DEVELOPMENTS IN JAPAN

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Abstract: Brief history of Japanese accelerator facilities and several topics in recent years are described from low to high energy regions.

In Japan, most of types of accelerators have been constructed and developed so far. Before the Second World War, a Cockcroft-Walton Type accelerator was constructed by Dr. S. Kikuchi in the Osaka University and contributed to the neutron physics in the early stage and small cyclotrons were constructed by Dr. Y. Nishina in the antecedent institute of the Institute of Physical and Chemical Research (ICPR) and also by Dr. Kikuchi. During the War, a large cyclotron was built already by Dr. Nishina. Nevertheless, the speed of postwar rehabilitation in accelerator facilities was very slow, while it was splendid particularly in the United States.

In 1955, the Institute for Nuclear Study (INS) was established in the Universituy of Tokyo, and a large variable energy cyclotron and then a strong-focusing electron synchrotron were constructed, in order to pursue the glorilus developments in many countries. After these, however, only an electron linac at Tohoku University was added and no large tandem Van de Graaff was installed in many years.

In 1970, the Research Center of Nuclear Physics (RCNP), Osaka University, and the National Laboratory for High-Energy Physics (KEK) were established, with much difficulty. One of the largest AVF cyclotrons in the former and a high-energy proton synchrotron in the latter were constructed on the basis of the well-developed accelerator technologies. Most of them were, however, rather too late to get to the international level of accelerator facilities.

Concerning synchrotron light source, some pioneering works were done by using the electron synchrotron and then, in 1970, the first dedicated storage ring for this purpose was constructed at the INS. The largest facility of synchrotron light source, Photon Factory, was established fairly in time at the KEK, in 1980, and followed by the other several facilities of moderate size.

In spite of the budgetary limitation mentioned above, Japanese accelerator physicists have endeavored so far to develop various important subjects in this field at many places, who have been supported by a favorable situation of high-level industrial technologies. In this paper, some typical activities and developments in Japan are reviewed briefly.

Electrostatic Accelerators

One of the biggest tandem electrostatic generators in the world, such as 20 MV, has installed recently at the Japan Atomic Energy Research Institute (JAERI). In the 1960's, however, no big one was installed at any institute, and it gave us much difficulty to contribute to nuclear physics in its most brilliant period, while various interesting technical developments in electrostatic generator have been carried out at the Kyushu University, as follows.

High-Gradient Electrostatic Accelerator Techniques[1,2]

At the Kyushu University, the construction of 10 MV tandem accelerator was started in 1972. Before that, this group had already developed a pellet chain and a magnetically suppressed acceleration tube successfully for their previous 6 MV Van de Graaff.

These important parts were improved farther for the tandem as shown in Figs.1 and 2. New acceleration tube has no longer magnetic suppressor but has carefully shaped diaphragm electrodes to eliminate electron and ion loading by coupling between adjacent units. The most interesting achievement is the success of baking

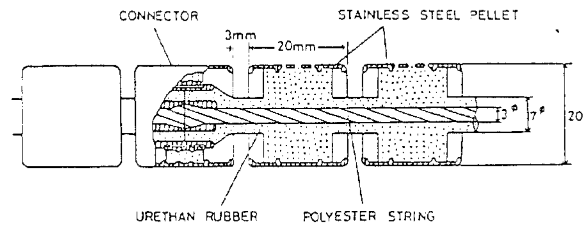

Fig.1. 20mmφ pellet chain

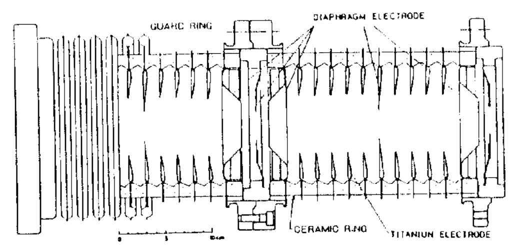

Fig.2. Acceleration tube with diaphragm electrodes

procedure of acceleration tube by means of low voltage arc discharge by using hydrogen gas flow. After the treatment of arc discharge current of 10 A for several hours, the terminal voltage was able to be raised up to 10 MV almost instantly and to 11 MV by conditioning for several hours more, while the maximum voltage was 6~7 MV before the new treatment. This treatment is very effective not only for degassing but also for eliminating fine metal scraps and fine grains of ceramic dust, and should be adopted by big electrostatic accelerators in future. Comparison of the achieved gradients of the existing tandem accelerator tubes is shown in Table 1.

Table 1, Comparison of Gradients of Existing Tandem Acc. Tube

	Original	HVEC-MP Upgraded	Extended	NEC	Kyushu Univ. Tandem
Terminal V(MV)	10	14	16	1.0/U	11
Overall Tube Gradient(kV/cm)	10.2	14.2	16.5	16.5	21.0
Inter-Electrode		(95% alive)		(75%)	(71%)
Gradient(kV/cm)	13.8	19.2	17.7	22.0	29.4
Overall Tube Length(m)		9.8		6.1	5.3

Rotating Disc Type Generator[3]

A compact high voltage generator, which makes use of a rotating disc type charge carrying device instead of the pellet chain, has been manufactured and used successfully up to 400 kV and 500 μA for the last several years, as the high voltage source for negative ion injection to the tandem machine mentioned above. The modified one was manufactured recently for application to ion im-plantation, which can generate 1 MV and 2.8 mA.

Linear Accelerator

Linear Accelerator developments extend over various kinds, such as radio-frequency quadrupole (RFQ)

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type, drift-tube type, disc-loaded type, disc-and-washer type(DAW).

Developments of four-vane RFQ, split-coaxial resonator RFQ and interdigital-H (IH) types have been investigated at the INS as heavy-ion injectors of a synchrotron. At the Tsukuba University, an interdigital-H type has been installed as a post accelerator of the 12 UD tandem Pelletron, which was originated by Dr. H. Morinaga at Munich Technical University.[4] At the IPCR, the world's first variable-frequency linac was constructed as an injector to the main separated-sector cyclotron of the heavy-ion acceletator facility. At the KEK, an Alvarez type linac stabilized by post couplers was investigated to upgrade the previous injector linac of the 12 GeV proton synchrotron (PS). On the other hand, the 2.5 GeV electron injector linac has been added with a positron generator linac both for the e^+-e^- collider (TRISTAN) and for the storage ring of synchrotron light source (PF).

The followings are some of these developments.

RFQ Type Linacs

At the INS: the RFQ linacs are being developed for acceleration of heavy-ions. A four-vane structure at operation frequency of about 100 MHz is suitable for acceleration of medium mass ions. It is considered, however, that the required TE 210 like mode is disturbed its field uniformity by a positioning error of the vanes and a variation of the intervane capacitance due to the modulation, and an inductive loop for feeding rf power also. These should be controlled with capacitive end-tuners and / or inductive side-tuners. The first trial was carried out by constructing a test cavity of 1 m in length (LITL), to test the feasibility of single-loop coupling as well as to develop various mechanical problems. The sufficient field uniformity was obtained by adjusting end-tuners. The acceleration test of the LITL was successfully performed with ions of q/A = 1 ~ 1/7, in 1983, which was the world's first achievement of heavy-ion acceleration with RFQ linac.[5] Following the LITL's success, the longer RFQ cavity (TALL) is being constructed, as shown in Fig.3. Sufficient field uniformity is obtained by adjusting side-tuners in addition to end-tuners. Acceleration test is now being prepared[6].

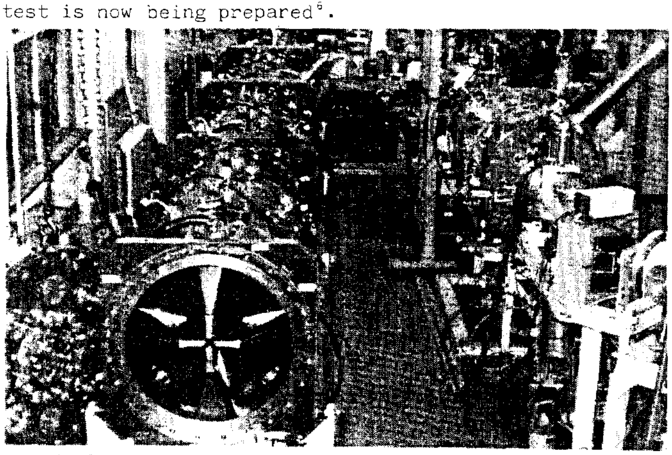

Fig.3. Four vane RFQs at INS. LITL on the right and TALL on the left as one fases.

Another new type split-coaxial RFQ structure with modulated vanes is also being studied for acceleration of very heavy ions with q/A > 1/60. With a 1/4 scaled model, basic and technical probledms are being studied.

At the IPCR: an Alvarez-type linac structure with a chain-like electrode configuration is being studied in order to apply the RFQ scheme to acceleration of particles in the medium velocity region. The essence is to develop a structure which can improve the effective shunt impedance of the RFQ structure by separating the acceleration and focus functions in space.

As a basis of the resonator, a cylindrical cavity excited at a TM-010 mode has been chosen. Installed in a cylindrical envelope, the structure looks like a multi-stem Alvarez linac. However, the distribution of the electric field along the beam axis is rather different from that of the Alvarez type. From the measured axial and radial field distributions by model studies, the energy gain per cell and the focusing strength was calculated. For an axial voltage gradient of 1 MV/m of the TM-010 mode, an energy gain of 1.4 MeV/m was found with transit time effects included, for the singly charged projectile with stable phase at the crest of rf. The calculated energy gain is much larger than that expected for an Alvarez linac having the same field gradient and cell length. The focusing field gradient in this example is 18 kV/cm across 20 mm gap between poles.[7]

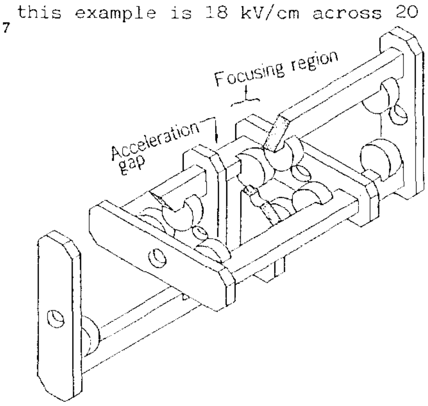

Fig.4. Schematic View of the Linac with Chain-Like Electrodes.

IH Type Linac

At the INS: electrical properties of a ridged IH resonator have been studied systematically. It is shown that the ridge plays an important role to improve the gap voltage distribution along a beam axis and a good voltage distribution is obtained by introducing a pair of wing tuners as well as end ridge tuner as shown in Fig.5. A prototype linac demonstrates the operational capabilities of the tuners, which is designed to correspond to a 1/4 scale model of the first stage linac for very heavy ion acceleration. Obtained performance confirmed for this structure to work excellently with the inductive wing tuners and end tuner, without an appreciable decrease in shunt impedance.[8]

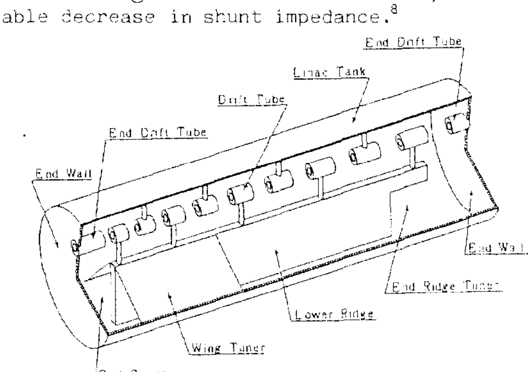

Fig. 5. A schematic drawing of the Wing Tuner and the End Ridge Tuner.

Following to the successful study of IH structure at the INS, a bigger linac of the same idea (TILAC) have been constructed as a booster of the 1.6 MV tandem Pelletron, at the Tokyo Institute of Technology, as shown in Fig.6.[9] Acceleration tests have been performed successfully by using H, C, O and Cℓ ions from the tandem Pelletron. The shunt impedance is estimated at 180 MΩ/m. The linac is followed by a second IH linac which has no wing tuner and focusing element because of the ions sufficiently accelerated and bunched with the first booster. The structure is, therefore, almost the same as of the post accelerator at the Tsukuba University mentioned above.

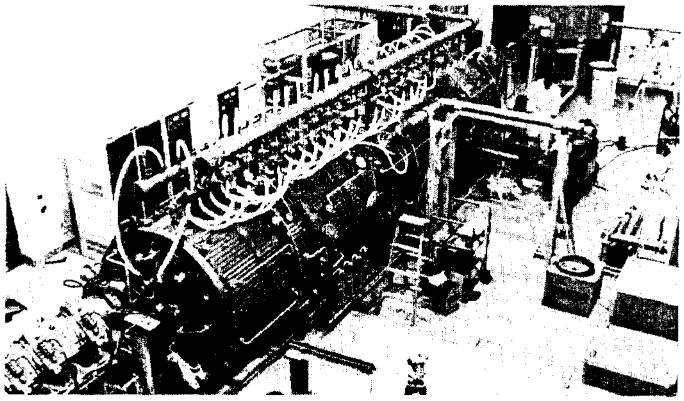

Fig.6. Completed IH Linac at the TIT.

Variable Frequency Linac[10]

At the IPCR, which is called RIKEN in Japanese, a heavy-ion linac (RILAC) whose acceleration frequency is tunable according to q/A of ions has been constructed as a prestripper part of a heavy-ion accelerator complex facility, as mentioned later. Of the greatest importance to success in the project was development of an accelerating structure with the resonant frequency tunable over a wide range. Construction of the RILAC was started in 1975. Effective shunt impedance measured on the completed cavity, including transit time effects is 180 MΩ/m at 17 MHz and 44 MΩ/m at 45 MHz. The first beam acceleration by the first resonator was achieved in 1979 and through the whole six accelerating structures in 1981. At present, RILAC is accelerating ions of various elements ranging from hydrogen to gold at different acceleration frequencies. Acceleration of heavier ions is feasible as far as their q/A remains larger than 1/28. Fig.7 shows the schematic structure.

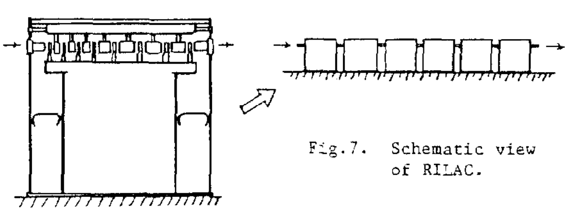

Fig.7. Schematic view of RILAC.

Contrary to ordinary fixed frequency heavy ion linacs, power consumption is smaller for acceleration of heavier ions by the use of frequencies lower than those for lighter ions. Since the power consumption is relatively small, the continuous operation is possible. The CW mode has simplified the RF circuits and the control system of the accelerator. The energy of accelerated ions is 0.6 MeV/u at the lowest and 4.0 MeV/u at the highest frequency.

Cyclotron

AVF Cyclotron

At the INS and RCNP: AVF cyclotrons were completed in 1975, whose K-numbers are 70 and 140, respectively. After these, commercial ones of various K have been installed at many places for applications.

The biggest and most excellent is the one at the RCNP, which has a three-sector, single dee structure. A $\lambda/4$ coaxial resonator with a sliding short can be excited in CW or pulse mode by a MOPA system. The dee voltage is stabilized within 10^{-4}.[11] The energy resolution better than 10^{-4} is obtained by a high-resolution magnetic spectrograph, RAIDEN, with a tandem beam monochrometer system.[12] An atomic beam type polarized ion source with ANAC ionizer is used. The currents of polarized beam at target position are about 500 and 100 nA for achromatic and monochromatic transportations, respectively. Acceleration of horizontally polarized beam has been performed. A Wien filter followed the ANAC ionizer rotates the spin of the beams into horizontal plane, before injection to the cyclotron.[13] The lifetime of the PIG source for heavy ion is prolonged up to 20 hours for nitrogen gas by using heat-insulated tantalum cathode. A pulsed power supply is used to get high charge states. Metal ions are also accelerated by back-bombarding method. Various ions up to argon are accelerated.[14]

Separated Sector Cyclotron (SSC)

Intermediate energy accelerator complex facilities, based on SSC as a main accelerator, are under construction at the IPCR as mentioned above and also being studied at the RCNP.

Linac-SSC System: At the IPCR, the completed RILAC will be connected to a SSC which is under construction. The first beam is expected in 1986. In order to upgrade this facility, a lot of new developments have been engaged in. Some of the unique developments are as follows.[15]

Table 2. Characteristics of beam from the RIKEN SSC

Maximum energy per nucleon	
proton	210 MeV
^{3}He	185 MeV/u
deuteron, alpha	135 MeV/u
Heavy ion	540 $(q/A)^2$ MeV/u
Energy resolution	0.05 %
Emittance	1.25π mm·mrad
Time resolution	200 ps

Movable Box Type Resonator[15]--- A couple of rf resonators having a delta-shaped dee electrode are installed. Because of synchronous operation with the injectors and single turn extraction, the rf system is required to work in a frequency range of 20 to 45 MHz and to generate an acceleration voltage as much as 250 kV.

A new type of resonator covering such a wide frequency range has been designed. It is of compact coaxial structure of half wave length (2.1m(H)x3.5(W) x1.6m(D)); the dee of radial span of 2.7m is supported by vertical stems. The resonant frequency is varied by moving the boxes surrounding these stems instead of a conventional movable shorting plate or movable panel. Fig. 8 shows a schematic view of this resonator where arrows indicate the electric current flow.

The advantages of this type of resonator are as follows: Since the large change of resonant frequency can be obtained by the small movement of them; the necessary height of the resonator becomes short. Furthermore, the current densities at the sliding short fingers become much lower than those of the movable shorting plate type.[15]

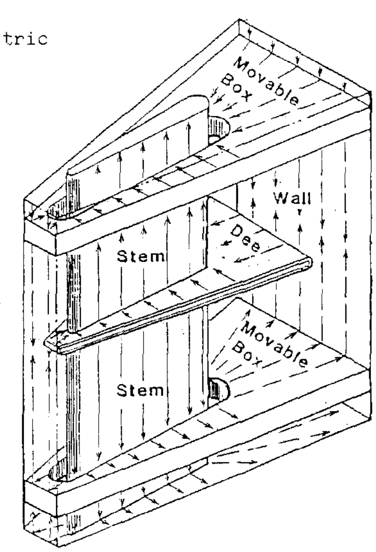

Fig.8. Movable Box Resonator.

CIM/DIM Control System --- For controlling a large number of slow response instruments such as power supplies for magnets and position controllers, conventional CAMAC modules have been widely used. However, the use of many CAMAC modules is not always economical. It often increases the load of a control computer and reduces the system reliability.

In order to overcome the disadvantages of CAMAC modules, two types of interfacing modules have been developed. The first one, CIM(communication interface module), is mounted in a CAMAC crate. The second one, DIM(device interface module), is placed in one or several instruments. A CIM/DIM system plays a role of local control in addition to an interfacing system, while a control computer plays the role of central control. A powerful control system has been realized by using these modules. Only seven CAMAC crates are used in the control of the SSC and the beam transport system. If conventional CAMAC interfacing modules were used, approximately thirty crates would be required.[17]

AVF-SSC System: At the RCNP, a two-stage system of an injector cyclotron and a SSC is proposed as shown in Table 3.[18]

Four-spiral-sector ring cyclotron has been designed as shown in Fig.9. The orbit analyses based on the measured magnetic field of a 1/4.5 scale model show that the design of the magnet is satisfactory.

Table 3 Characteristics of the cyclotrons

	Injector AVF	Spiral Sector Ring Cyclotron
No. of sector magnets	4	4
Sector angle		34°~ 39°
Injection radius (cm)		135
Extraction radius (cm)	67.5	375
Magnetic field max. (kG)	20.0	15.5
Proton energy max. (MeV)	26	300
Alpha energy max. (MeV)	38	340
K-value	70	280
No. of trim coils	8	35
RF frequency (MHz)	20~33	20~33
Voltage max. (kV)	50	500
RF power (kW)	60x2	200x2

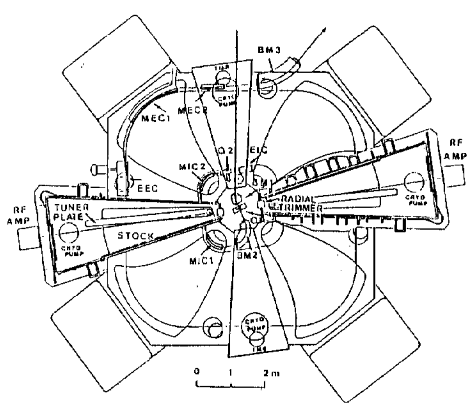

Fig.9. Plan view of proposed SSC.

An aluminum single-gap cavity was constructed for the ring cyclotron and cavity voltage above 275 kV was achieved in preliminary test. The cavity covers a frequency range of 20 to 33 MHz with a rotatable tuner plate sliding on a stock and the phase compression ratio of the cavity can be adjusted around the value of 3 by radial trimmer as shown in Fig.9.[19]

The analysis of the orbit properties was done also for the injector cyclotron. The results show that the azimuthal dee width should be matched for peak voltage acceleration condition to reduce the longitudinal to radial phase space coupling effect.[20]

The aim of this accelerator system is to get high quality beams of protons and light ions accelerated up to the intermediate energy region for precise nuclear studies in high resolution. An energy resolution better than 10^{-4} can be obtained with a new method of flat-topping without flat-topping deceleration.

Achromatic transportation is performed by the beam transport system between the injector and the ring cyclotron. For longitudinal phase space, the energy deviations of the extracted beam from the injector cyclotron are inverted at the injection point of the ring with a two-cavity beam buncher system. Consequently, the sinusoidal energy deviation of the injected beam can be compensated in the ring by adjusting the phase compression ratio.[18]

Synchrotron and Cooler Ring

Several years ago, a high-energy heavy-ion accelerator complex(NUMATRON) was proposed and related preparatory studies have been carried out at the INS. Beside various linac studies as mentioned above, a test accumulator ring (TARN) of 10 m in diameter was constructed and a combination of multiturn injection and rf-stacking was succeeded using proton, molecular hydrogen, α-particle and carbon from cyclotron. Vacuum pressure of the ring reaches to a region of 10^{-12} Torr. Completed the stochastic cooling experiment of low-energy proton and recently α, the TARN is being upgraded to TARN II which will be a synchrotron and cooler ring of 25 m in diameter, as described later.

Stochastic Cooling at TARN[21]

Stochastic cooling experiment is successfully carried out. The particles are 7 MeV protons and 28 MeV α's accumulated in TARN with rf stacking.

The stochastic cooling program was proposed to study feasibility for such a low-energy beam. The technique has been established through works at CERN. Following the remarkable success at the Antiproton Accumulator ring, they constructed the Low Energy Antiproton Ring, LEAR, where beams of 50 and 175 MeV are cooled. The successes with such low-energy beams at LEAR and TARN suggest that stochastic cooling is applicable to an energy region of nuclear physics.

Feedback system: The main feature of the cooling at TARN is an application to a slow beam, v/c=0.12. For this purpose, travelling-wave couplers for the pickup and the kicker were designed and fabricated. The inner conductor is a helix, of which the geometry is determined to attain a signal velocity equal to the beam velocity and a high coupling impedance in a required range of 20 ~ 100 MHz.

Figure 10 shows the block diagram of the feedback system from pickup to kicker. The notch filter consists of an end-shorted coaxial cable and two 100Ω resistors. With this cable and an additive short cable, the resonant frequency is finely tuned to the beam's revolution frequency of around 1.1 MHz. The amplitude and phase responses are optimized with the two resistors. Consequently, this notch filter transforms the beam signal to a correction signal with a voltage proportional to the momentum error of a particle. The system bandwidth is defined with the high- and low-pass

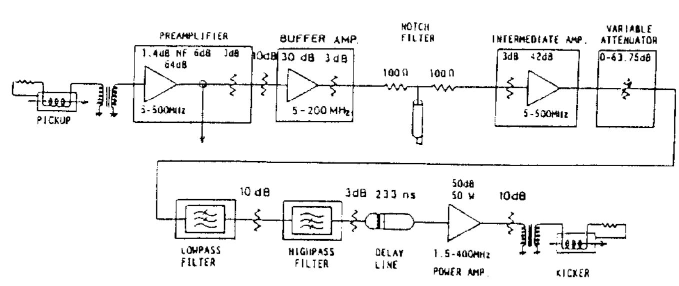

Fig.10. Block diagram of feedback system.

filters. The system gain is adjusted with a variable attenuator. The transmission time of the beam signal from pickup to kicker is adjusted with a delay circuit of a 1 ns step.

Experimental results

Figure 11 shows a typical Schottky signals before and after cooling. The system bandwdth is 20 ~ 95 MHz, and the number of α's is $1.2\text{X}10^7$. The initial momentum spread of 1.2% in FWHM is reduced to 0.06% after 420 s long cooling.

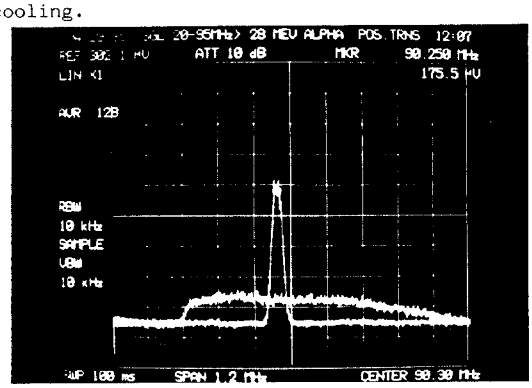

Fig.11. Schottky signals at the 80th harmonic before and after cooling of 420 s, for 28 MeVα particles.

Time variation of the momentum spread is compared between two cases of different system gains for protons of 10^7. At 99dB, same as in Fig.11, the momentum spread decreases exponentially with time and reaches the final value. The 1/e cooling time is 85 s and the final momentum spread is 0.08%. At increased system gain of 109 dB, the cooling time is shortened to 26 s, but the final momentum spread is increased to 0.125%. These dependences of cooling time and final momentum spread on the system gain are compared with theoretical calulation. According to a Fokker-Planck equation describing the momentum cooling process, the cooling time is inversely proportional to the system gain, and the final momentum spread is directly proportional to its square root. The above experimental results agree well with the theoretical calculation.

Upgrading of TARN (TARN II)[22,23,24]

Upgrading of TARN is now in progress, as shown in Fig.12. Added capabilities are as follows:
1) synchrotron acceleration up to 1.3 GeV for proton and 450 MeV/u for q/A = 0.5, 2) electron cooling as well as stochastic cooling aimed a resolution of 10^{-5}, 3) beam extraction and internal beam target device, etc.

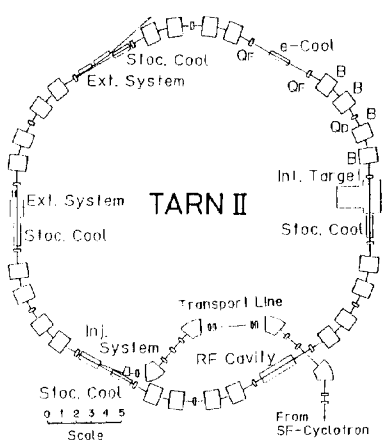

Fig.12. Layout of TARN II, which is a synchrotron and cooler under construction.

Electron Cooling at TARN II[24]-- The ring can be operated in two modes. The first mode is used for synchrotron accelration, and the second mode is for the cooling mode, in which the dispersion function is zero at the cooling section and the amplitude function is as small as possible at the internal target section. The circulating beams can be transfered between two modes. Most of parts of the device are under construction. Electron beam test will start in 1985, and the cooling experiments of ions in TARN II is expected in 1987.

Electron Beam Facility[25,26]

In 1967, an electron linac of 300 MeV was completed at the Tohoku University and then excellent works in nuclear physics have been carried out so far. Recently, in order to improve a low-duty factor, 0.1%, of the existing linac which has a peak intensity of 100 mA and makes coincidence experiments difficult, a pulse stretcher ring of 150 MeV have been installed. The principle is well known since the ALIS project at Saclay.
However, no pulse stretcher had actually been constructed. In addition to the present necessity in the existing facility, it was thought to be important to confirm a feasibility to supply a continuous electron beam, considering a future facility of higher-intensity higher-duty and higher energy electron beam. An energy compression system is used to improve energy spectrum of the beam to be suitable for the stretcher. A third integer resonance in the horizontal plane is used to extract the beam. Stored electrons are losing their energy by synchrotron radiation and then reach the energy of the resonance successively. The extracted beam maintains its continuity as shown in Fig.13.

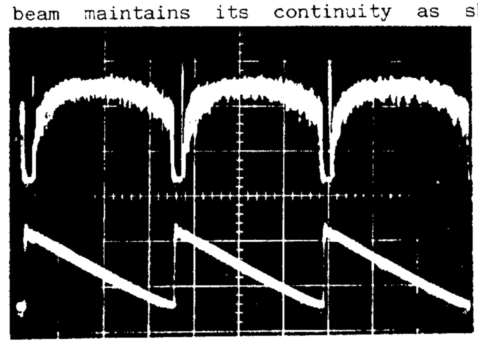
Fig.13. Time dependence of beam intensities. Upper: stretched, Lower: circulating.

$e^+ - e^-$ Collider (TRISTAN)

At the KEK, an $e^+ - e^-$ collider facility (TRISTAN) (30 GeV x 30 GeV) is under construction.[27] Injector linac is common to the synchrotron light source facility (Photon Factory:PF) as mentioned above.[28] An accumulator ring (AR) is now the commissioning stage. Such high-energy project is a serious stage of international competition and, therefore, various developments have been performed to upgrade the energy and luminousity at the tight situations in budget and site.

10 Tesla Superconducting Dipole Magnet[30]

To survey the possibility of high field accelerator magnets, an extensive study has been made at the KEK.

Recently a dipole magnet (1 m long and cold bore 90 mm) with tight holding structure was built using the NbTi/Cu superconducting cable, the coils and holding structure of which were immersed in the atmospheric pressure superfluid helium in a horizontal 1.8 K cryostat.

After three trainings at 4.2 K, the dipole coils and holding structure were cooled down to 1.8 K. In the first excitation at this temperature with a current of 6,340 A, the field at the center of the beam aperture rose to 9.3 T, corresponding to a record maximum field of over 10 T and then the dipole made a big quench.

Figure 14 shows the schematic end structure of the superconducting dipole magnet. KEK will push its development project of high field dipole magnets for the uses in future accelerators.

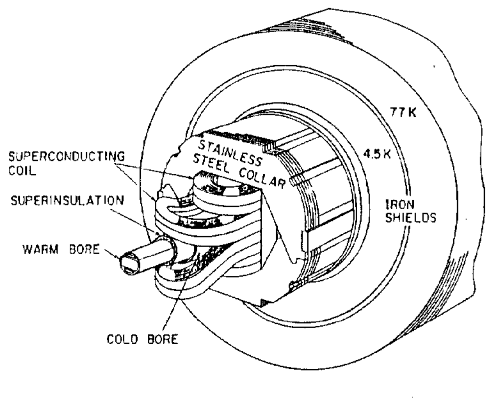

Figure 14. Schematic end structure of the KEK 10 Tesla dipole magnet.

Superconducting rf cavity

Research and development of superconducting rf cavities at KEK has been concentrated to study the feasibility of the large scale application of S.C. cavities to the TRISTAN Main Ring (MR).

According to the encouraging results of the 500 MHz single cavity experiments [31], a three-cell niobium structure has been built and tested in the TRISTAN AR.[32,33] Maximum field gradient of 4.3 MV/m was achieved, 10 mA beam was stored at 2.5 GeV and 1 mA beam was accelerated to 5 GeV by S.C. structure alone. Higher order mode couplers worked as expected and no problem on the beam instability was observed. Controlling of frequency, amplitude and phase worked satisfactorily.[32,33]

A five-cell structure is now being prepared which has larger iris aperture, input and higher order mode couplers on the beam tube. Two such structures will be installed in AR. Some tens of five-cell structures are planned for MR in the future.

More fundamental program of the research on the S.C. cavities such as the reseach on material, manufacturing and surface treatment is also progressing. Recently one single cavity was tested and showed the accelerating field gradient of more than 7.6 MV/m at the first cool down. The cavity was made of the commercial niobium and the sheet material was annealed in the vacuum furnace wrapped with Ti foil to improve the thermal conductivity of niobium.[34]

Developments for Future Accelerator

In order to discuss a direction of developments for future accelerator, a study group have been assembled and are studying a feasibility of $e^+ - e^-$ linear collider in TeV region. At the same time, the development of Lasertron is in progress as a hopeful candidate for a high-power rf source.

A prototype of the Lasertron, Mark-I, generated the rf-power of 1.6 kW successfully in 1984, which is a seal off type with a conventional Sb-multialkali photocathode. Further study was started to achieve a peak-power of 1 GW, which is partly supported by the Joint Japan - US Collaboration program in high energy physics. A demountable Lasertron, LT 300, of 47 MW are planned as a first step. The effort have been concentrated on the following:
1) to develop computer codes for the simulation of the beam dynamics, 2) to study the electron gun system with GaAs or GaAsP photocathode, 3) to make a preliminary test of the photocathodes.[37]

Synchrotron Light Source

PF at the KEK: The PF ran steadily throughout the last two years, which is normally operated with the filling of 150 mA at 2.5 GeV and the lifetime at 100 mA is 15 to 20 hrs. Recently, the maximum values of 520 mA was obtained at 2 GeV and the lifetime at 100 mA reached to 25 hrs. The wiggler has been installed which is a superconducting vertical type. The maximum field is currently limited at 5 tesla not by the wiggler itself but by the rf power and thermal load on the beam line. The undulator installed is the world's longest one, which has 120 poles (60 periods) and a length of 360 cm.[35]

UVSOR at the IMS: At the Institute for molecular Science, UVSOR is dedicated to the research use in molecular science and related fields, which has a storage ring and injector synchrotron of 600 MeV. Achieved values are energy of 750 MeV, current of 200 mA, lifetime of 2 hrs at 100 mA. A wiggler of 4 tesla and an undulator of 0.7 tesla (35 periods) were also installed, recently.[36]

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