IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

STATUS OF KEK TRISTAN PROJECT

T. Nishikawa and G. Horikoshi
KEK, National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

Abstract

Status of the KEK TRISTAN project, the Phase I of which has been approved since 1981, is reported with an emphasis on its accelerator design and construction. The design of accelerator complex has mostly been fixed. Construction of accelerator enclosure and production of accelerator components are under way with a target day for the first e^+e^- collisions in 1986.

§1. Introduction

At KEK, the National Laboratory for High Energy Physics in Japan, a 50 ∿ 60 GeV electron-positron collider is under construction. This accelerator complex is nicknamed as TRISTAN i.e. an abbreviation of Transposable Ring Intersecting Storage Accelerators in Nippon. When the original TRISTAN plan was proposed in 1973, it consisted of three separate rings installed in the same tunnel i.e. two superconducting rings and one conventional ring.[1] Thus the initial of TRISTAN came from the "Tri-Ring ....", and the original plan aimed at high-energy colliding beam experiments of various types such as pp, $e^{\pm}p$, e^+e^- and $\bar{p}p$ by choosing a set of intersecting storage rings.

Since the original TRISTAN plan was proposed, an extensive design study has been made from accelerator view points and physics requirements. Then the TRISTAN plan was enlarged so as to have the largest ring that can be accommodated on the KEK site in the Science City of Tsukuba.[2] The total circumference of the accelerator enclosure is increased from 2 km of the original version to approximately 3 km. This makes it possible to accelerate electrons up to 25 ∿ 30 GeV and protons to more than 300 GeV.

In order to materialize the refined TRISTAN plan within the frame-work of available budget, manpower etc, the entire TRISTAN plan has been divided into phases. In Phase I, the conventional ring for e^+e^- collisions is constructed together with the accelerator enclosure which is capable of future extended plans. The TRISTAN Phase I project has been approved by the Japanese Government and the construction started in April 1981 as a five-year program. The ground breaking ceremony was held on November 19, 1981 on the occasion of the KEK tenth anniversary.

TRISTAN Phase I aims at searches for new particles such as toponiums, Higgs bosons, heavy leptons and free quarks and at studies of electro-weak interactions, QCD, etc. Among the four intersections, two of them are to be instrumented with rather standard detectors used by mostly national teams, TOPAZ and VENUS.[3] Consonant with the spirit of ICFA guide line, KEK has asked for international participation by physics groups for other two intersections.

This article gives the status of the TRISTAN Phase I construction including its engineering and technical progress as well as the general description of the accelerator design.

§2. General Design of TRISTAN Phase I

A layout of the TRISTAN Phase I is shown in Fig. 1. The present KEK site comprises an area of ∿ 1 km × 2 km and the main accelerator enclosure just about fits the site.

The e^+e^- complex consists of three accelerator stages. First, electrons are accelerated to 2.5 GeV by a 400 m long linear accelerator, a part of the Photon Factory (KEK synchrotron radiation facility). The

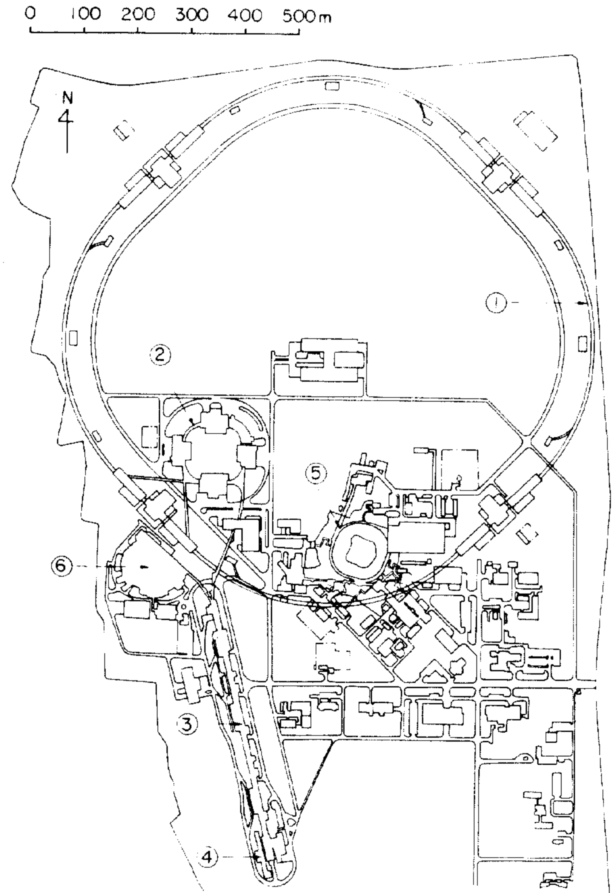


Fig. 1 Site layout of the TRISTAN Phase I project. 1. TRISTAN main ring. 2. TRISTAN accumulating ring. 3. 2.5 GeV electron linac. 4. Positron source linac. 5. 12 GeV proton synchrotron. 6. Photon Factory electron storage ring.

linear accelerator has been in operation since March, 1982.[4] Positrons will be produced with a separate 200 MeV high peak-intensity electron linac and fed into the 2.5 GeV linac at the source end.

In the second stage, electrons and positrons are accumulated and accelerated up to 8 GeV in an intermediate storage ring prior to be injected into the main ring. The purpose of the accumulating ring is to reduce the damping time in the main ring as well as to boost the injection energy. Incidentally, the accumulating ring can be used in the storage collider mode with a maximum center-of-mass energy of 13 GeV and with an optimum luminosity of about 2×10^{31} cm^{-2} sec^{-1} at 12 GeV. The circumference of the accumulating ring is approximately 377 m and its tunnel with two experimental halls are brought to completion. Both the bending and quadrupole magnets of the accumulating ring have been delivered and installed inside the tunnel. First beam test is expected in the fall of this year.

The large main ring has a fourfold symmetry with four long straight sections, the middle point of which being at the interaction area. The total circumference is approximately 3 km including four long straight sections of 194.4 m each. A large portion of the long straight sections is allotted for RF accelerations in order to overcome the synchrotron radiation loss for attaining higher energies with a rather smaller ring,

0018-9499/83/0800-1983$01.00© 1983 IEEE

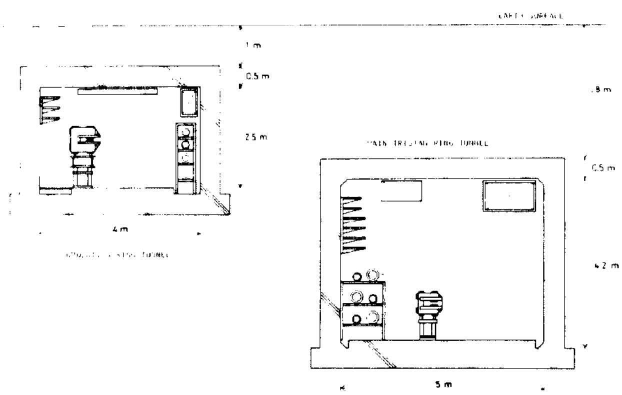


Fig. 2 Cross section of the TRISTAN accumulating and main ring tunnel in the arc.

for instance, compared to the LEP ring. The total available RF power is assumed to be 25 MW in maximum. This should satisfy the requirement to generate an accelerating voltage of 400 MV/turn and to achieve a design goal of the collision luminosity of about 1 × 10^{31} cm^{-2} sec^{-1} at the center-of-mass energy of 60 GeV. The development of superconducting RF cavity system may lead the maximum attainable energy as high as 85 GeV, or nearing the energy of Z^0 production.[5] The length left for colliding beam detector system at the middle of straight sections is as short as 6 m in order to obtain a high luminosity with a mini-β system. It should be noted here that such a long straight section has also the capability to build interaction area for ep collisions as a future plan.

Cross sections of the tunnel in the accumulating ring and the main ring are shown in Fig. 2. The floor level of these rings are at an elevation of 5 m and 11 m below the ground level, respectively. A large cross section of 6 m in width and 4 m in height of the main tunnel is enough to allow future expansion. The experimental halls at the main ring will be built about 16 m below the ground level and will measure 27 m and 53 m along and across the beam direction, respectively. They are large enough to move the complete assembled detector system and electronics hut in and out of the interaction region. The construction of the main ring just started from the SW experimental hall that is nicknamed as Fuji hall.

The general design parameters of TRISTAN Phase I are listed in Table 1. Fig. 3 gives the design luminosity as a function of beam energies. The arrangement of bending and quadrupole magnets in an octant of the main ring is shown in Fig. 4 together with evolution of the horizontal and vertical betatron functions and the dispersion function along the beam orbit. The betatron function around the collision point is taken as low as 1.12 m and 0.07 m in horizontal and vertical directions to attain the design luminosity as high as possible. For this purpose, a couple of quadrupoles are located 3 m away from the collision point.

It is apprehended that the beam-cavity interactions limit the stored current in the main ring due to single-bunch beam instabilities through the higher-mode excitation as is observed at PEP and PETRA. In addition, use of an extraordinary long cavity system may cause beam instabilities due to multi-transversal of bunches

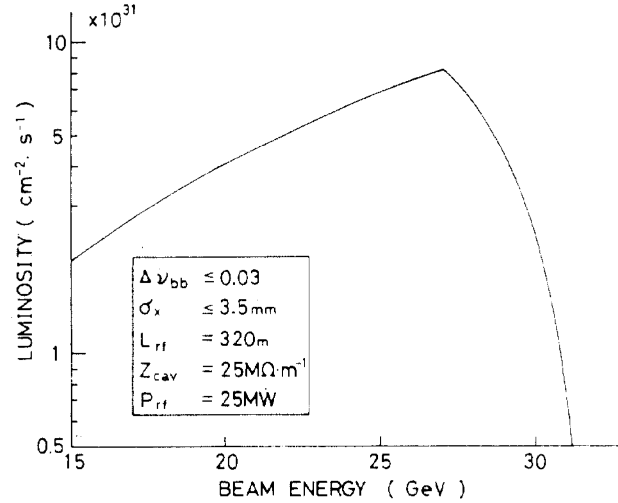


Fig. 3 Design luminosity of the TRISTAN main e^+e^- collider.

Table I General Parameters of the TRISTAN Phase I

I. Collider Rings

	Main Ring	Accumulating Ring
Circumference	3018.1 m	377.0 m
Average radius of curved section	346.7 m	47.7 m
Bending radius	246.5 m	23.2 m
Long straight sections	4 × 194.4 m	2 × (19.5 + 19.1 m)
Total length of RF sections	509.4 m	38.1 m
Total length of RF cavities	320 m	29.6 m
RF frequency	508.6 MHz	508.6 MHz
Revolution frequency	99.33 kHz	0.795 MHz
Radiation loss per turn	290 MeV	4.9 MeV
RF peak voltage	382 MV	10 MV
Beam Energy	30 GeV	6 GeV
Injection Energy	6 − 8 GeV	2.5 − 3 GeV
Experimental Insertions	4 × 6 m	2 × 5 m
Max. design luminosity	8 × 10^{31} $cm^{-2}\cdot s^{-1}$ (at 27 GeV)	2 × 10^{31} $cm^{-2}\cdot s^{-1}$ (at 6 GeV)
Betatron function at coll. point (β_x^*/β_y^*)	1.12 m / 0.07 m	2.0 m / 0.1 m
Beam size at coll. point (σ_x^*/σ_y^*)	0.434 mm / 0.027 mm	0.71 mm / 0.036 mm

II. Injector linacs

	Main Linac	Positron Generator
Beam Energy	2.5 − 3 GeV	200 MeV
Total length	400 m	80 m
RF Frequency	2856 MHz	2856 MHz
Pulse width and repetition	∿ 1 ns × 50 pps	∿ 1 ns × 50 pps
Peak current	500 mA(e^-) / 5 mA(e^+)	10 A(e^-)

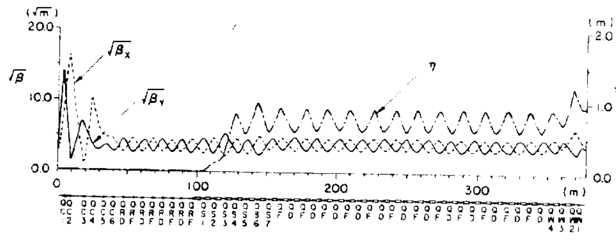


Fig. 4 An octant of the TRISTAN main e^+e^- ring Magnet lattice. (β: betatron fn., η: dispersion fn.)

through a multi-cavity system in a duration less than radiation damping time. A careful study on these instabilities is under way at KEK in connection with the design and development of RF acceleration system.

§3. Design and Construction of Accumulation Ring and Main Ring

Since the project was started, the design and construction have been extensively continued. The settled schedule of the design and construction is shown in Table II. Now, the TRISTAN Phase I project is at the end of the second FY of the five-year program. Almost all the components for the accumulating ring (AR) are completed and ready for installation in the AR enclosure. While, the construction of the main ring (MR) which was started in 1982 behind by one year to AR is under midway. Design of fundamental components such as main magnets are already fixed and some of which are under process of manufacturing, while some parts are still in the design stage. In the following, present status of AR and MR construction is presented in order.

3.1. Accumulation Ring

3.1.1. Magnet System

The magnet system of AR is composed of 56 bending magnets, 86 quadrupole magnets, 40 sextupole magnets and other magnets including skewed quadrupole and steering magnets. The bending magnet is of a C-type. As shown in Fig. 5, each bending magnet unit is composed of two iron cores and one set of coil. Two C shaped straight iron cores each having length of 1.29 m are placed on a common girder with an angle of 3.214 degree and have a common coil. Such a structure is just the same as of the bending magnet of the 12 GeV proton synchrotron at KEK.

86 quadrupole magnets are grouped into two types. One is regular type (78 in number) and the other is insertion type (8 in number). The bore diameter of the regular type magnet is 80 mm, and the one of the insertion type is 120 mm. Regular type magnets are used in regular cells, RF sections and in dispersion suppresser cells, while the insertion magnets are in low-β sections near the colliding points. It is certified that the regular Q-magnets can be excited up to 20 T/m with a

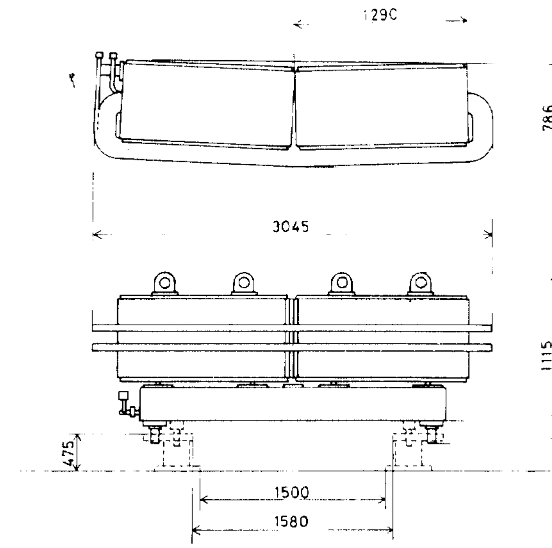


Fig. 5 Bending magnet of accumulating ring.

saturation of less than 5 %. The magnet system of AR is designed to have 0 dispersion in the RF sections and at the colliding points, and to have the least β at the colliding point. To adjust the magnetic field of AR, a large flexibility in the power supplying system is necessary. For the purpose, 86 Q-magnets are grouped into 25 families each of which has an independently adjustable power supply. On the other hand, the bending magnets are all connected to one power supply and energized as a whole. As a field correction system, 40 sextupole magnets having a bore diameter of 92 mm are also distributed around the ring.

Skewed-quadrupoles and a wiggler as well as the steering system are prepared. The wiggler magnet has a role to reduce the damping time in the injection period.

After the beam is injected and stacked in AR, the beam is accelerated up to 8 GeV, extracted and transfered to MR. This process of acceleration will be repeated in every 120 sec or less. Acceleration must be done in 30 to 60 sec, and all magnets are operated being synchronized to the acceleration timing pulse. The current patterns of the magnet can be easily changed by changing the digital reference source. The stabilities of power supplies are better than 10^{-4} for the bending and Q magnets and 10^{-3} for the other correction magnets such as sextupole and steering magnets.[6]

All bending and Q magnets have been completed and installed in AR enclosure. Works of precise setting within ± 1 mm have just been finished. Correction magnets will be installed soon. All power supplies are to be prepared by the end of March and the overall test including some fine adjustment will begin soon.

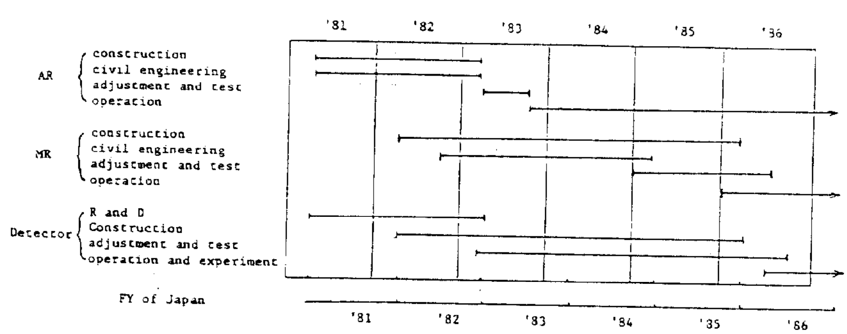


Table II Time schedule of TRISTAN Phase I project.

3.1.2. RF Acceleration

The RF acceleration system is composed of two stations each of which will be installed in east and west long straight sections, respectively. Each station has 4 cavities and is driven by one klystron. The klystron generates a continuous RF power of 1 MW at 500 MHz. The RF power is divided into 4 cavities by a two stage ladder system of magic tees. The cavity is a DAW type with a vertical radial stem structure.[7] The cavity has 12 cells of $\lambda/2$ type and is 3.6 m in length. The cavity is made by pure steel plate rolled and welded, and then the inner surface of the cavity is copper plated to a thickness of 0.2 mm. A test using a prototype cavity with 5 cells showed a maximum input power rating of 55 kW which corresponds to E_{acc} of 0.9 MV/m.[8] The klystron is a vertical set-up type with a vapor cooled collector. The conversion efficiency of the beam power to that of RF power is not less than 55 %. Both klystrons and cavities are already ordered and under the performance test in the manufacturer.

Besides the DAW structure, an APS is under test with a slot coupled model cavity.[9]

3.1.3. Vacuum[10]

The vacuum system of AR is made of all aluminum alloy. By "all aluminum", it means that there is no material transition such as being employed in the other electron stroage ring i.e., photon factory of KEK, PEP and PETRA. To realize the all aluminum system, many new techniques have been developped.[11] Merits in adopting the aluminum as a main material are as follows: (i) samll weight which will result in a low cost of the system, (ii) high thermal conductivity which makes it easy to cool down the radiant power of SOR and (iii) easiness in forming process. In addition, the latest test shows that some of the aluminum alloy is a very good material for ultra-high vacuum use.

Two kinds of vacuum ducts are prepared for AR. One is "B-tube" and the other is "Q-tube" (Fig. 6). The B-tube is used in the bending magnet and its cross section is divided into two spaces, i.e., one is for the beam and the others for the distributed ion pump (DIP). DIP is the main pump in the vacuum system of AR. Q-tubes are used in most of the straight sections. The cross section of the Q-tube is just the same in shape as the beam space of the B-tube. Both B and Q tubes have two holes for the cooling water. The structure of the vacuum duct makes it easy to provide a small slit for the SOR light outlet without spoiling the cooling efficiency. A U-shaped structure which is for the heater pipe for baking is also prepared.

As mentioned above, each B-tube has a unit of DIP assembly of about 2.5 m in length being built in the DIP space. Utilizing the magnetic field of bending magnets, the DIP units work as the main pumps of the system. In a test operation, it has been certified that the final attainable pressure of DIP is lower than 1×10^{-11} Torr and the pumping speed is about 100 $\ell\ s^{-1}\ m^{-1}$. In addition to these DIP's, 80 sputter-ion pumps (SIP) of 30 $\ell\ s^{-1}$ in speed are distributed around the ring. Bulk-getter pumps of Al-Zr alloy are also employed near the colliding points where the DIP cannot be used for a length of about 25 m and, at the same time, it is difficult to prepare the space for a conventional SIP. Fourteen roughing pump units each of which consists of a TMP of 50 $\ell\ s^{-1}$ and a small RP are installed in every 25 m. For the operation of these roughing units, two control systems each of which is mounted on a movable carrier will be used. Connecting this controller to one of the roughing units by a cable, the controller can talk with the control computer system.

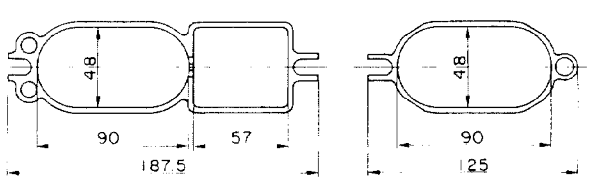


Fig. 6 Cross section of beam duct of AR. B-type (left) and Q-type (right).

3.1.4. Beam Monitor[12]

As the beam diagnostic system, beam position monitors, synchrotron radiation monitors, beam current monitors and tune measurement set up are being prepared. A set of four button electrodes detects the beam position both in the horizontal and vertical directions. Two kinds of synchrotron light monitors, one works in the visible region and the other in the x-ray region, get informations on beam profile, beam current and beam bunch shape. As a main beam current monitor, a DCCT type current monitor will be installed in the ring.

3.1.5. Beam Transportation

The beam transportation line from the 2.5 GeV electron linac to AR is 350 m in length, and consists of 47 quadrupole and 26 horizontal bending magnets. This line transports both electron and positron beams from the 2.5 GeV electron linac to AR without any change of current polarity of every quadrupole magnet. For the purpose, the betatron phase advance between the adjacent groups of bending magnets is π, and the line is almost achromatic for both electrons and positrons. Injection of the beam is accomplished by a set of two septum magnets and the beam enters through a Be window of 0.3 mm in thickness which isolates the ultra-high vacuum in AR from the high vacuum in the Beam Transportation line.

Design and construction of the beam extraction system from AR are also going on. By now, the design of the extraction system has been fixed.

3.1.6. Control[13]

In principle, it is preferable to control all accelerators of TRISTAN facility by one system. But, in KEK, the 2.5 GeV electron linac is partly the injector for the electron storage ring of Photon Factory facility and has been operated by a control system from a separate building. This style of operation will be continued after the completion of TRISTAN Phase I, and AR and MR are operated by the central control system of TRISTAN. The main part of the TRISTAN control system is an N-to-N network of about 20 16-bit minicomputers linked by optical fiber cables. There is no host computer. Any computer in the net-work can talk with another computer in the network and can exchange any kinds of information. Eight of these minicomputers will be supplied by the end of March and be ready for AR operation. NODAL interpreters are systematically used as the language of control programs.

3.2. Main Ring

The design and construction were started last April. By now, design work has been finished in some fundamental components such as main magnets and the cross section of the beam duct in the ring, but some components are still in the design work. Many components are the same in principle as in AR but large in number by a factor of 9. Of course, some components are rather different because of the very high beam energy.

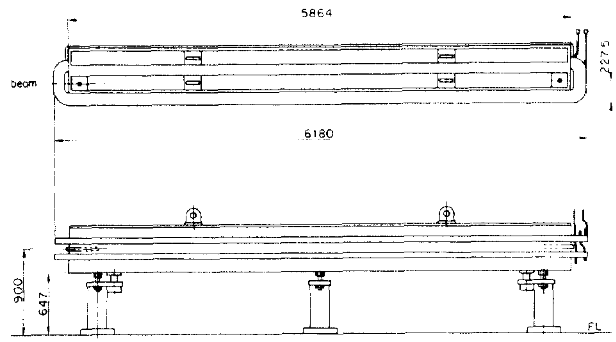
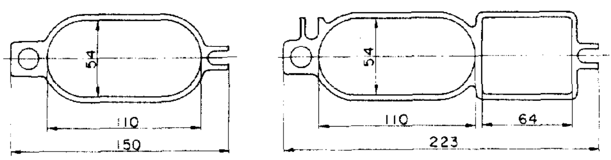


Fig. 7 Bending magnet of TRISTAN main ring.



main ring. Q-type (left) and B-type (right).

3.2.1. Magnet

The bending magnet of MR is rather small in cross section because of low magnetic field ($B \sim 0.4$ T) and has a length of 5.7 m. Such a shape of long but small in cross section presents a difficult problem as to its supporting method. To minimize the deformation, a three points supporting method was employed. Expecting a successful introduction of superconducting cavities in MR in future operation, we have designed MR magnets so as to be able to accelerate the beam up to an energy of 42 GeV. For this purpose, the bending magnet has an enough size and performance to generate the field of 0.55 T. In Fig. 7, a schematic diagram of the bending magnet with its supporting system is shown.

3.2.2. Vacuum

In the vacuum system of MR, the most serious problem is the shielding against intense radiations of SOR. The critical energy of the SOR is about 260 keV and it requires for the shielding a lead sheet of about 10 mm in thickness. The way to support the lead sheet is now under discussion. In Fig. 8, the cross sections of B- and Q-tubes are shown.

3.2.3. RF Acceleration

The energy loss of electrons and/or positrons in MR is about 290 MeV/turn. To compensate this amount of energy loss, a powerful RF acceleration is needed. For the RF sections, spaces the total length of which is 320 m are prepared. In the design, 120 RF cavities each of which has 9 cells of $\lambda/2$ type and operates in 500 MHz region are to be installed around the ring. These cavities are driven by 30 klystrons of 1 MW which are the same as being used in AR. A Modified DAW structure as well as an APS type are being studied for MR main cavities.

Besides these main cavities, Landau cavities will be inserted in the RF sections. The Landau cavity is driven by RF of about 1 GHz, i.e. twice of the main frequency. The combination system of main and higher harmonic RF cavities (double RF system) increases the synchrotron frequency spread and suppresses the bunched beam instability and the synchro-betatron resonance.[14] A prototype of APS cavity for this purpose has been tested leading to a high shunt impedance of about 26 MΩ/m.

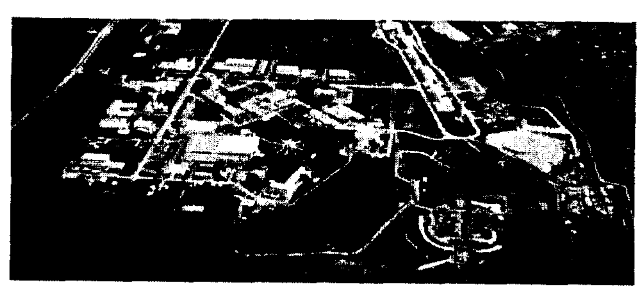
§4. Development of Superconducting Cavity (SCC)[5-15]

The maximum energy of electron and/or positron beams attainable in the MR depends on the accelerating voltage. With the system of conventional cavities, the accelerating voltage is about 400 MV/turn. This limits the beam energy to 30 GeV with the luminosity L of 1×10^{31} cm^{-2} s^{-1}.

It is expected that the SCC can get rid of these limits. An experiment being made on a prototype SCC of 500 MHz has successfully given a maximum accelerating field of more than 6.5 MV/m. This means that a much higher beam energy could be attainable in MR. In AR, a short section is alloted and ready for the test operation of SCC with a beam. Now the research and test on the power feeding coupler are going on. The new cavity with coupler ports for input and HOM couplers is under testing. Q_0 at low field was 3.8×10^9 and E_{acc} reached 3.8 MV/m. The frequency tuning mechanism is able to control the cavity frequency in the range of ± 440 kHz within an accuracy of 100 Hz.

References

1) T. Nishikawa, Proc. Int. Symp. on High Energy Phys. (Tokyo, 1973) p.157.
T. Nishikawa, Proc. US-Japan Seminar on High Energy Accelerator Science (KEK, 1973) p.209.
2) Y. Kimura, Proc. XI-th Int. Conf. on High Energy Phys. (Madison, 1980) p.859.
3) T. Nishikawa, S. Ozaki and Y. Kimura, to be published in "Surveys of High Energy Physics" (Academic Press).
4) J. Tanaka et al., Nucl. Instr. Meth. 177 (1980) p.101.
J. Tanaka et al., Proc. XI-th Conf. on High Energy Accelerators, CERN, July 7-11 (1980) p.242.
J. Tanaka et al., Proc. Japan/USA Seminar on Synchrotron Radiation Facilities, Honolulu, Nov. 5-9, 1979 (Nucl. Instr. Meth. 177 (1980) No.1.).
5) Y. Kojima et al., Jpn. A. Appl. Phys. 21, No.2, (1982) P.L-86.
6) K. Endo et al., this conference, Y26.
T. Kubo et al., this conference, Y27.
7) K. Takata et al., IEEE NS-28, (1981) p.2873.
S. Inagaki et al., Proc. 4-th Acc. Sci. and Technol. (1982) p.257.
S. Inagaki et al., this conference, G31.
8) S. Noguchi et al., Proc. 4-th Acc. Sci. and Technol., (1982) p.255.
9) S. Giordano, IEEE Trans. Nucl. Sci. NS-12, No.3, (1965) p.213.
T. Nishikawa et al., R.S.I. 37, (1966) p.652.
10) H. Ishimaru et al., this conference, Y17.
11) H. Ishimaru et al., IEEE Trans. on Nucl. Sci. NS-28, No.3, June, (1981) p.3320.
12) Y. Mizumachi et al., this conference, W63.
13) S. Kurokawa, Private communication.
14) T. Suzuki et al., this conference, R27.
15) Y. Kojima et al., Jpn. J. Appl. Phys. 20, No.2, (1981) p.L-145.



A bird view of KEK site focussed on TRISTAN AR and Photon Factory facility.