The 6th Symp. on Accelerator Science and Technology, 1987, Tokyo, Japan (© Ionics, Tokyo, 1987)

INITIAL OPERATION OF THE TRISTAN ELECTRON-POSITRON COLLIDING BEAM ACCELERATOR

Y. Kimura and H. Baba

KEK, National Laboratory for High Energy Physics
Oho-machi, Ibaraki-ken, Japan

INTRODUCTION

The last accelerator of the TRISTAN project, the main electron-positron colliding beam ring was completed in November 1986. The accelerator commissioning was marked rather dramatically by an observation of the first electron-positron collision event at 48 GeV, the world highest center of mass energy, on November 19. On the same day of five years ago the ground breaking ceremony of the TRISTAN project took place.

After a series of preliminary physics runs which were carried out in a period from December 1986 to February 1987,[1] the first regular operation of the TRISTAN accelerator for the physics data take was started in May 1987 and lasted for about three months till the end of July. In the course of the operations, the accelerator performances have rapidly been improved. The peak luminosity, which was about 3 ∿ 5 × 10^{29} $cm^{-2}sec^{-1}$ in the last winter run, reached about 8 × 10^{30} $cm^{-2}sec^{-1}$ in the summer run. Correspondingly, the integral luminosity could be increased to about 200 nb^{-1}/day from the initial figure of about a few nb^{-1}/day. Four experimental groups, VENUS, AMY, TOPAZ, and SHIP, whose detectors are located in the TRISTAN experimental halls, Fuji, Oho, Tsukuba and Nikko, respectively, have accumulated about 1500 hadronic collision events in total so far for a total integrated luminosity of about 15 pb^{-1} at 50 GeV and 52 GeV in the center of mass energy.

In the following, the TRISTAN accelerator system is outlined first, and performances of the main colliding beam ring are summarized with emphasis on the operational experiences gained in the initial accelerator operations. On-going program for upgrading the TRISTAN accelerator will also be described.

OUTLINE OF THE TRISTAN ACCELERATOR SYSTEM

The accelerator complex of TRISTAN consists of an injector linac system, an accumulation ring, AR, and a main colliding beam ring, MR.[2] Disposition of the TRISTAN accelerators in the KEK site is illustrated in Fig. 1. The injector system includes a 2.5 GeV main linac, a 200 MeV high current electron linac to produce positrons, and a 250 MeV linac to preaccelerate positrons before injection into the main linac. AR, which is a storage accelerator with a circumference of 377 m, accumulates electrons and positrons from the injector linac and accelerates to 6.5 ∿ 8 GeV to transfer to MR. MR has a four-fold symmetrical structure that four quadrant arcs of 347 m in average radius are joined by four 194 m-long straight sections.

Two electron and two positron bunches, circulating in clockwise and in counter-clockwise, respectively, collide to each other at the middle of the four straight sections, where the experimental detectors are installed. There are four experimental halls corresponding to each collision point. As shown in Fig. 1, the halls are named Fuji, Nikko, Tsukuba, and Oho after the famous land mark located in respective direction.

The injector linac was completed in 1982 and has steadily been operated to provide 2.5 GeV electron beams to the Photon Factory electron storage ring and TRISTAN AR. AR was commissioned in 1983 and operated in 1984 and 1985 for accelerator developments and for producing two bremsstrahlung beams with internal molybdenum targets. Those photon beams were converted into electron beams and used for energy calibration of the lead-glass counters for the colliding beam experiments in MR.

In 1986 a new experimental facility attached to AR has started its operation to make the synchrotron radiation research in the energy region of 5 ∿ 6.5 GeV. For the moment, it has one photon beam channel which accommodates two experimental set-ups, one for studies on X-ray diffraction under super-high pressure and the other for medical applications.

An experiment to collide an electron bunch with a positron bunch was also made in AR. The collision luminosity was measured with a luminosity counter developed for use in MR. For the magnet lattice tuned to a low-beta optics of the horizontal and vertical beta-functions of 2 m and 0.1 m, respectively, at the collision point, the luminosity of 1 ∿ 5 × 10^{29} $cm^{-2}s^{-1}$ was achieved in the beam energies ranging from 2.5 GeV to 5 GeV. As electrostatic beam separators were not yet installed in AR, the accumulated beam current could not exceed a few mA per beam due to the beam-beam instability at the injection. Experimental attempts to pursue a possibility of studying bottom quark physics with AR are going on. For that purpose, the luminosity higher than 10^{32} $cm^{-2}sec^{-1}$ will have to be reached.

Parameters of the TRISTAN accelerators are listed in Table 1. Those figures given in parentheses indicate the design or target values.

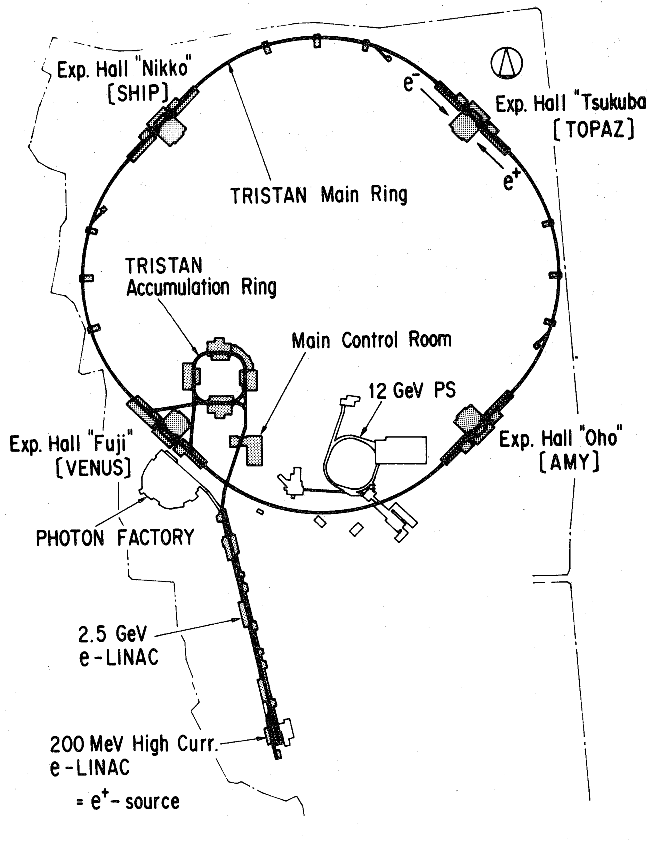

Fig. 1 TRISTAN accelerators in the KEK site.

Table 1 Parameters of the TRISTAN accelerators

Injector linac	
Energy	2.5 GeV
Repetition	25 (50) pps
Peak current, e^-/e^+	50/10 mA
Pulse width	1 ∿ 1.5 ns
Positron generating linac	
Energy	200 MeV
Peak electron current	10 A
Thickness of conversion Ta target	2 rad. lengths
Energy of accelerated positron	250 MeV
TRISTAN AR	
Circumference	377 m
Bending radius	23.2 m
Injection energy	2.5 GeV
Extraction energy	7.4 (8) GeV
RF frequency	508.6 MHz
RF voltage at 7.4 GeV	20 MV
Max. single bunch current	40 ∿ 50 mA
TRISTAN MR	
Circumference	3018 m
Bending radius	246.5 m
Injection energy	7.4 (8) GeV
Max. energy	26 (30) GeV
RF frequency	508.6 MHz
RF voltage at 26 GeV	260 MV
Total number of cavity cells	720 (963)
Total shunt impedance	4750 (6180) MΩ
Max. single bunch current	3.5 (4) mA
Max. two e^+ and two e^- bunch current	9.5 (15) mA
Number of collision points	4
Beta-function at collision point (hor./ver.)	1.8(1.6)/0.1(0.07)m
Vertical-horizontal emittance ratio	2 ∿ 3 %
Max. luminosity	$0.8(1)\times10^{31}cm^{-2}\cdot s^{-1}$
Max. integrated luminosity per day	200 nb^{-1}
Beam life	2∿3 (4∿5) hr.

INITIAL OPERATION OF THE TRISTAN MAIN COLLIDING BEAM RING

The TRISTAN main colliding beam ring, MR, was put into the first operation with beams on October 15, 1986. Accelerator developments for beam injection and acceleration progressed very satisfactorily, and collisions between an electron and a positron bunches were first tried on November 14 at 48 GeV in the center of mass energy. Since then the operation of the TRISTAN accelerator system has been cycled as summarized below.

- October 15 ∿ December 5, 1986: Operation for the MR commissioning.
- December 10 ∿ December 19, 1986: First physics run for preliminary data take by VENUS and AMY at 50 GeV in the center of mass energy.
- January 22 ∿ February 20, 1987: Continuation of the previous operation cycle.
- March 4 ∿ March 20, 1987: AR operation dedicated to the synchrotron radiation researches at 6 GeV.
- May 13 ∿ July 25, 1987: First regular operation cycle for physics data take by VENUS, TOPAZ, AMY, and SHIP. The collision energy was 50 GeV till the middle of June, then increased to 52 GeV.

Operation statistics of the TRISTAN accelerators are given in Table 2. As a whole, the accelerator elements of MR have worked as designed. Only exception is the electro-static beam separators. In MR, sixteen separator units are used to keep a vertical distance of about a few mm's between electron and positron beams at the four collision points during the injection and acceleration periods. The units were so designed that a voltage as high as 240 kV could be applied between the positive and negative electrodes separated by 8 cm each other. In the operation with beams, however, it was found that they could not stand a voltage higher than about 80 kV. This phemomenon is now understood to be caused by an electric breakdown which a wake field generated by beams induces at around the supporting structures of the electrodes. A new type of the separator has been designed and is under construction.

Table 2 Operation statistics of the TRISTAN accelerators (Dec. 1986 ∿ July 1987)

Period	Dec.10∿Feb.20	May 13∿July 25
Total operation time	778 (100)	1444 (100)
Colliding beam experiments	392 (50)	898 (62)
Accelerator developments	284 (37)	420 (29)
Operation halt	102 (13)	126 (9)
Halt due to AR and MR failures	102 (13)	49 (3)

(in hours (%))

During the long shutdown period from February 20 to May 13, 1987, MR had several large-scaled modifications. The largest was replacement of the cathode material of the distributed sputter ion pumps from aluminum to titanium.[3] Although the newly developed aluminum cathode showed good pumping function in the laboratory tests, it deteriorated considerably when installed in the ring, where vacuum pressure reached as high as 10^{-6} ∿ 10^{-7} Torr as a result of irradiation of the vacuum pipe wall by intense synchrotron light. The present ion pumps with titanium cathode worked as expected in the operation after May and made it possible to lengthen the beam life time to about three hours.[4]

A typical operation pattern of MR is illustrated in Fig. 2. It shows variations of the total beam current and the beam life time extending over a whole day. The terraced increase of the current indicates the beam injection. Usually MR is filled with two positron bunches first, then with two electron bunches. To form an electron or a positron bunch of about 2 mA in MR, an electron or a positron bunch of 15 ∿ 20 mA accelerated in AR has to be transferred to MR twice. To complete the beam injection in MR, then, requires eight injection and acceleration AR cycles and takes about 20 minutes. Beam losses arising from single beam as well as two beam instabilities limit the efficiency of the beam transfer from AR to MR to about 50 ∿ 60 %. The latter instability arises from insufficient beam separations at the collision points due to the beam separator trouble mentioned above. To stabilize the beam in MR, eight dipole wiggler units consisting of three horizontally deflecting magnets were installed in the wiggler straight sections at the symmetry points of the MR quadrant arcs. The present wiggler system could halve the radiation damping time and increase the energy spread by three times and the emittance by ten times, and proved to be indispensable to the beam injection in MR.

The electron and positron beams injected are accelerated to the top energy in about 2 minutes and brought to collision after changing the lattice parameters from those for an injection optics to those for a low-beta optics, in which the beta functions at the collision points are squeezed to about 1.8 m horizontally and 0.1 m vertically. This optics transfer was performed by changing the strength of the insertion quadrupoles in many small steps so that the operating betatron tunes did not cross the stop-bands on the tune diagram. As seen from Fig. 2 no conspicuous beam loss is observed in the acceleration and optics transfer processes.

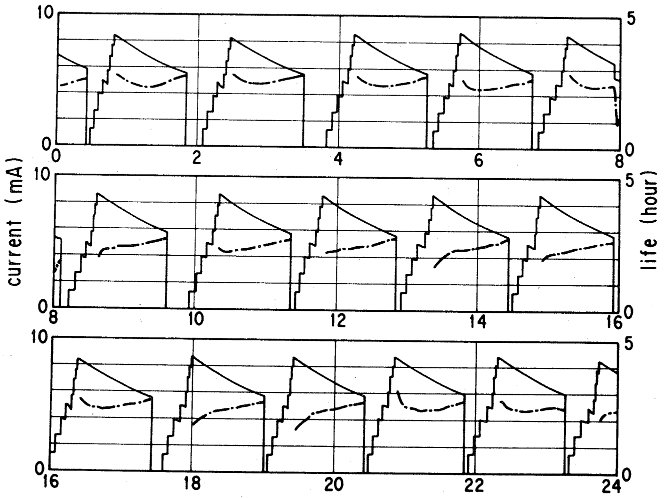

Fig. 2 Total current and life time of the MR beam recorded through 24 hours on July 21, 1987.

The highest luminosity attained so far is about 8 × 10^{30} $cm^{-2}\cdot sec^{-1}$. This is mainly limited by the beam current which can be injected in MR, and still below a limit imposed by beam-beam effects, although the beam-beam tune shift was measured to be fairly close to a standard limiting value of 0.03. To achieve the luminosity as high as possible, operating parameters of MR were finely adjusted so as to make the beam emittance and its horizontal-vertical ratio as small as possible. The beam emittance can be controlled by shifting the accelerating RF frequency and the emittance ratio by adjusting the closed orbit with the orbit correcting dipoles. Details of the MR beam tuning are to be presented separately to this Symposium by the TRISTAN beam development group.[5]

In the regular operation, a data taking run continues for about one and a half hours after starting the beam collision, and terminates for the next injection. An optimization of the accelerator operation for the highest integral luminosity leads to such a running cycle under the present beam life time condition. As indicated in Table 2, an amount of the running time lost by the accelerator failure is fairly small. An accelerator element which showed the most frequent breakdowns was the RF system.[6] Those were interlocked interruptions of a part of the RF system, which were mainly caused by excessive power reflection to klystrons associated with discharge in the cavities and klystron failures such as deterioration of tube vacuum due to gas burst. At present MR are equipped with eighty units of the nine-cell APS cavities and twenty

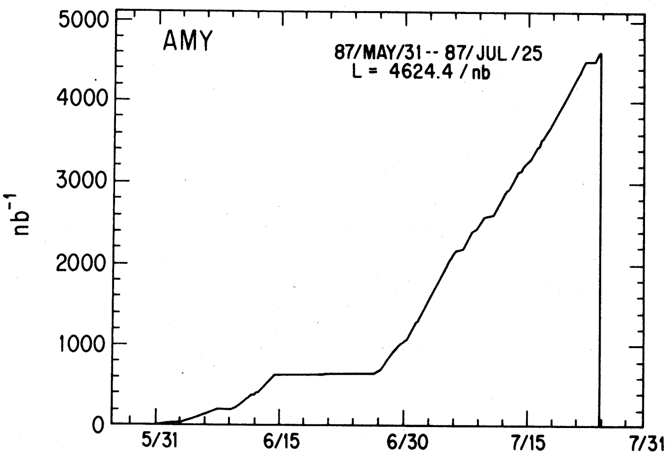

Fig. 3 Integrated luminosity accumulated by AMY group.

pieces of 1 MW klystrons operated at 508 MHz. Average fault rates of those cavity and klystron systems were measured to be about 0.01 hr^{-1}/cavity and 0.01 hr^{-1}/klystron in a total operation time of 1200 hours in June and July 1987. Those failures, however, could be recovered very quickly. As the accelerating voltage as sufficient as it can sustain the circulating beam when two klystrons stopped working was applied to the cavities, the beam was rarely lost by such RF troubles. Figure 3 illustrates how the integrated luminosity accumulated by AMY group varied through the operation from May 31 to July 25, 1987.

ACCELERATOR UPGRADING PROGRAM

An immediate upgrading of the TRISTAN MR is to raise the present beam energy of 26 GeV to about 28 GeV in the operation starting from October 1987. This is done by installing additional twenty-four units of the nine-cell APS cavities in the Oho RF section. For further increase of the beam energy, it is inevitable to use superconducting RF cavities to keep the electric power consumption within a limit of about 100 MW. In April 1986, a two-year program started to construct a superconducting RF system consisting of thirty-two units of five-cell niobium cavities and a liquid helium refrigerator to cool down the cavities. When the system is completed and installed in the Nikko RF section, the beam energy is expected to reach as high as 33 GeV. The construction of the superconducting cavity follows the development work at KEK extending over fifteen years. A prototype cavity was constructed and tested with the AR beam in February 1986. The measured Q-value of the cavity was 3.5×10^9 at a low field and 1.8×10^9 at 4.1 MV/m. The maximum accelerating field of 4.5 MV/m was achieved at 4.2 K after RF aging. Figure 4 shows the first MR cavity delivered from the manufacturer this summer. The MR cavity consists of two independent five-cell units which are coupled together only mechanically and enclosed in a liquid helium cryostat. Measured Q-values of those two five-cell units, a and b, are plotted in Fig. 5 as a function of the accelerating field.

The other upgrading program is to build superconducting quadrupole magnet systems to improve the collision luminosity. As shown in Fig. 6, superconducting quadrupole magnets, QCS, located very close to the collision point in the experimental detector allow a considerable reduction of beta-functions, i.e. beam size, at the collision point. Construction of a part of the system has started this fiscal year aiming at completing the whole system for the four experimental insertions in about two years. A model magnet and cryostat fabricated last year are shown in Fig. 7. The superconducting quadrupole magnet is designed to produce a field gradient as high as 70 T/m and will be able to double the luminosity attained with the present iron core insertion quadrupole magnet system.

Acknowledgement

The authors wish to thank Professors T. Nishikawa, S. Ozaki, and G. Horikoshi for directing them to carry out the successful initial operation of the TRISTAN colliding beam ring.

REFERENCES

1) G. Horikoshi and Y. Kimura, Proc. of the US Accelerator Conf., Washington 1987, to be published.
2) Y. Kimura, Proc. of the 13th Int. Conf. on High Energy Accelerators, Novosibirsk 1986, to be published.
3) H. Ishimaru et al., E-1 and E-2 in this Symposium.
4) K. Kanazawa et al., E-3 in this Symposium.
5) K. Satoh et al., B-2 in this Symposium.
6) M. Ono et al., D-18 in this Symposium.

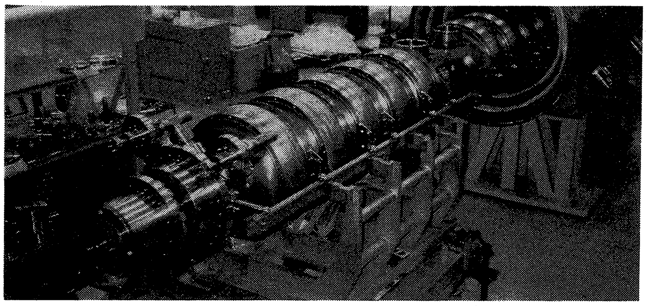

Fig. 4 Superconducting niobium cavities and cryostat for MR.

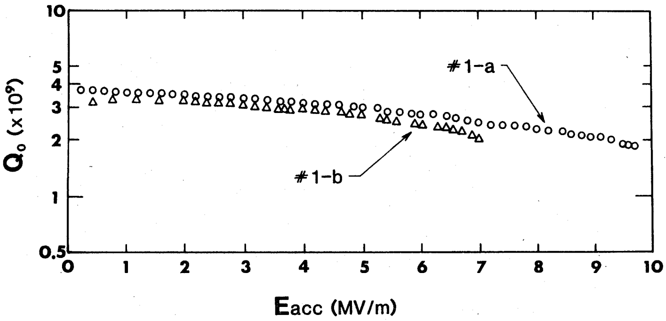

Fig. 5 Measured Q-values of the first two superconducting five-cell cavities for MR, a and b, as a function of the accelerating field.

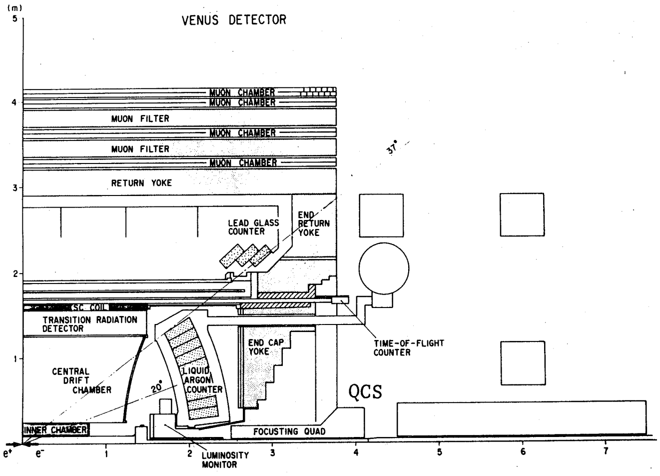

Fig. 6 Configuration of the mini-beta experimental insertion at VENUS with use of the superconducting quadrupole magnets, QCS.

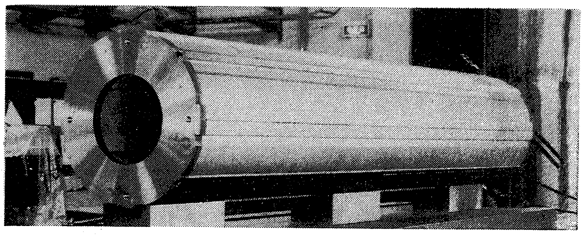

Fig. 7-a Model superconducting quadrupole magnet.

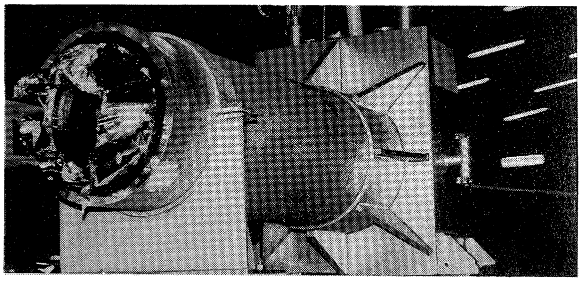

Fig. 7-b Cryostat for the model superconducting quadrupole magnet.