CONSTRUCTION AND OPERATION OF THE TRISTAN ACCUMULATION RING

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ABSTRACT

The construction and operation of AR are documentally summarized. The construction of AR started in Apr. 1981 and the ground breaking ceremony was held on 19th of Sept. in 1981. The first acceleration of the beam up to 4.2 GeV was achieved on 19th of Oct. in 1983 and the beam energy of 6.5 GeV which is higher than the initial design energy was achieved on 4th of July this year. Some details of construction as well as of operation are given.

HYSTORICAL

The TRISTAN (phase I) is a large scale electron and positron accelerator complex composed of an accumulation ring (AR) of 120 m in diameter and an electron-positron colliding ring (MR) of 960 m in diameter[1-3]. AR receives 2.5 GeV electron or positron beam from the PF linac (the injector linac of Photon Factory facility), accumulates, accelerates to 8 GeV and injects the beam into MR. In the other mode, AR can storage electron and/or positron beam of 6 GeV. AR can work as a storage collider of 6 GeV, too. The MR accelerates these beams up to 30 GeV or more and brings these beams into collision. The TRISTAN project was approved in 1981 and the construction started in the fiscal year of 1981. At that time, most of the fundamental design of TRISTAN phase I had almost been finished and only the practical detailed design were left to be done. The ground breaking ceremony was held on 19th of Sept. in 1981 and civil engineering work of the accelerator enclosures began. After a year, in the fall of 1982, the tunnel for AR was almost completed and the machine assembling of AR was commenced in the tunnel. In Nov., the main magnets both bending and quadrupole magnets were carried into the tunnel and installed. It took almost seven months to accomplish the magnet system aligned within an error of about ± 0.1 mm. In parallel with these works, in Feb. of 1983, the construction of the injection line was also started. The total length of the line from the PF linac to AR is about 340 m. In Apr. of 1983, the construction and adjusting of the beam monitoring system went on[4]. The first accelerating cavity of 500 MHz was installed in one of the straight sections and after that a high power klystron was set in the west building of AR[5]. In parallel with the constructions in the tunnel, the construction of the control system went on[6-8]. The vacuum system was the first part being brought into operation through the computer system[9]. By the end of Sept., almost all parts of AR were ready for being operated from the central control room through the computer system. On 19th of Oct., the first operation of injection line was made and the electron beam was successfully introduced from the PF linac to the injection point of AR. On 16th of Nov., a trial to accelerate the beam with two RF cavities was made and successfully achieved the beam energy of 4.2 GeV, and on 15th of Dec., the beam energy of 5.2 GeV was achieved[10-12]. This energy was limited by the total accelerating voltage generated in the cavity. But the energy of 5.2 GeV was enough to be used in the detector calibration. Fig. 1 shows a synchrotron light spot of the circulating beam catched on a TV camera. Since March of 1984, the internal target system which was prepared for the detector calibraion has begun to work with the primary beam of 5 GeV, and the lead glass detector calibration has been started[13]. After that, in June, another RF cavity was installed in the straight section and, at the same time, the klystron was improved to deliver a higher power. A superconducting cavity of three cell type was also installed in the east straight section to make various kinds of test with and without beam[14,15]. On 4th of July, acceleraton and storage of the beam was tried again, and the beam was successfully accelerated to 6 GeV with three ordinary cavities and up to 6.5 GeV with the use of ordinary and superconducting cavity system in parallel. At the same time, holding of the beam at 6 GeV was also successfully accomplished. In Table I, main events in the progress of AR construction and operation are summarized.

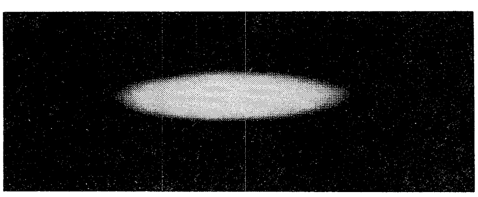

Fig. 1 Synchrotron light spot on a TV camera.

Table 1

Calender of main events in the construction and operation of AR

1981	
19, Sept.	ground breaking ceremony
1982	
Dec.	first installation of main magnet in the tunnel
1983	
Mar.	rough alignment of magnets
Jun.	completion of vacuum system for injection line
Jul.	completion of beam transport system of injection line
	completion of power supply for magnets
	assembling of vacuum system of AR
Aug.	final alignment of magnet system
	first operaton of vacuum system of injection line
Sept.	installation of RF cavity (DAW type)
	first operation of vacuum system of AR
Oct.	first operation of beam position monitoring system
	first operation of high power klystron
16, Nov.	first storage of 2.5 GeV beam
18, Nov.	first beam acceleration up to 4.2 GeV
15, Dec.	beam acceleration up to 5.2 GeV
27, Dec.	maximum beam current of 90 mA (2.5 GeV, multi-bunch)
1984	
10, Feb.	maximum beam current of 65 mA (2.5 GeV, single-bunch)
7-8, Mar.	simultaneous operation of two internal targets (3 GeV)
15, Jun.	first routine operation of internal target system (5 GeV)
4, Jul.	beam acceleration up to 6.5 GeV with normal and superconducting cavities
	beam storage at 6 GeV with normal and superconducting cavities

CONSTRUCTION

In the five-year construction schedule of TRISTAN, the time scheduled for the AR construction is two years. Because of the very short time for the construction, the schedule adjustment among the subgroups of AR construction group was one of the most troublesome problems. For the purpose of the schedule adjustment and regulation, a schedule center was set up.

In starting the assembling of machine in the tunnel, there were many problems to be solved and adjusted. In Aug. of 1982, the tunnel had been almost completed, but the other fundamental equipments such as lighting, power supply, cooling water supply, communication system and air conditioning system had not been completed yet. In the schedule, we were to begin the assembling work in Oct., a little before the completion of the tunnel. For the work, an enough amounts of lighting and power supply were necessary, and a tentative wiring was made. The high humidity was also one of the serious problems. In the summer season, the temperature in the tunnel was far below the dew point of the environemntal condition, and water was condensed on the wall of the tunnel and dripped down to the floor. By using thick polyvinyl curtains, the tunnel was seperated from the external atmosphere and a number of air drying machines were installed in the tunnel. This improved the conditions in the tunnel a little, but the effect was not enough. The space in the tunnel was too large, the seperation by the curtain was imperfect and the number of air drying machines was not enough. This problem must be considered again in the construction of MR.

Because of a small cross section of AR tunnel, there was no crane equipped. Special carriers were necessary to carry and install the main magnets, and carriers for bending and quadrupole magnets were designed and manufactured (Fig. 2). To avoid undersirable accidental contacts and collision, the carriers were so designed as to go around the tunnel along a guiding rail. The carriers carry the bending or quadrupole magnets, install and adjust the setting position within an error of ± 1 mm. It is expected that these carrier are also available in the MR construction.

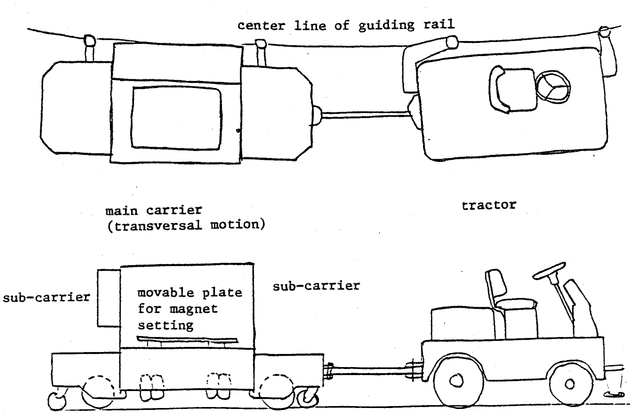

Fig. 2 A special carrier for the bending magnet.

In Oct. of 1982, a little before the completion of the AR tunnel, standard points (monuments) for the main magnets setting were precisely fixed in the tunnel within an error of ± 3 mm. At the end of Oct., the tunnel was completed and assembling of AR was followed. It was only ten months that was spent for the AR construction work in the tunnel. AR was completed at the end of Sept. of 1983.

The magnet system is composed of 56 bending magnets, 86 quadrupole magnets and other magnets including sextupole and steering dipole magnets. 86 quadrupole magnets are grouped into two types. One is regular type (78) and the other is insertion type (8). The magnet system of AR is designed to have zero dispersion in the RF sections and at the colliding points. To adjust the magnetic field of AR, a large flexibility is necessary in the power supplying system. To realize this flexibility, 86 quadrupole magnets are grouped into 25 families and the same number of independent adjustable power supplies were prepared for those families[16,17]. While the bending magnets are all connected to one power supply and energizied as a whole. These power supplies were installed in both east and west buildings and many water cooled aluminum busbar lines run from the buildings to the magnets through the tunnel ceiling.

Because the accelerating RF frequencies adopted in AR and MR are just the same, both RF accelerating systems for AR and MR are completely compatible with each other. There is no distinction between them. The RF group has been concentrating their efforts to develop a new cavity of high performance for the use of AR and MR[11,18]. In the first, disc and washer (DAW) type cavity was designed and manufactured, and the first two DAW type cavities were installed and used in the first operation. Although many higher mode resonances were detected in the cavity, no serious beam loss due to these higher mode resonances was observed.

The vacuum system of AR is made of all aluminum alloy[19]. To realize the all aluminum system, many vacuum components of aluminum have been developed. Aluminum conflat flange, aluminum bellows, gate valve of aluminum and electric feed through of aluminum and alumina ceramic are some of them. To reduce the number of flanges and save spaces, we have employed the in situ welding method in assembling of the vacuum duct in the AR tunnel. To make the welding reliable, an automatic welding machine for non circular pipe has been successfully developed. More than one hundred in situ weldings were made with the automatic machine and only a few leakages were found.

The injection line guides the beam from PF linac to AR. The line is composed of 47 quadrupole magnets, 26 bending magnets and beam duct of about 340 m in length. The guiding field design was made so that the betatron phase advance between the adjacent groups of bending magnets is π. This design makes the line almost achromatic for both electron and positron beams and makes it easy to adjust the field for both e^- and e^+ beams.

By the end of Sept. of 1983, the wholly computerized system was completed. All the control functions are executed through the touch panel system. It can be said that the smooth and successful initial operation of AR owes much to the wholly computerized control system[20-25]. The main part of TRISTAN control system is an N-to-N network of 16 bit minicomputers, and eight minicomputers are installed and worked for the AR operation.

OPERATION AND MACHINE STUDY

After the successful initial operation, an urgent objective of the accelerator study in AR was to accumulate the beam current in a single bunch mode as much as possible and to observe its stability. A single bunch with high intensity is likely to be unstable due to various reasons, especially the interaction between a circulating beam and an accelerating cavity. In AR, disc-and-washer (DAW) type cavities were intalled[11]. This type was a promising candidate for the TRISTAN main ring because of its high shunt impedance or its high accelerating field with small input power. In spite of its high shunt impedance, this has not been used for beam acceleration in the world. The DAW cavity has a lot of deflecting modes as well as longitudinal modes, which may, an accelerator theory predicts, interact with the circulating beam and make it unstable. Therefore we had to know how the DAW cavity interact with the single bunched beam and also to know whether the high intensity beam becomes unstable by the other reasons[26,27]. These results would be very valuable for designing the main ring and foreseeing beam behavior in it.

It was easy to find a good operating point in the betatron tune diagram and to accumulate a single bunched beam. We first met a vertical coherent instability which limits the current typically below 0.3 mA. By the chromaticity correction with sextupole magnets we were able to cure the vertical instability, which is supposed to be the head-tail instability, and increase the current further. During these improvements COD correction was a very important process. We completed the COD correction system within a short period and were able to minimize the COD below 1 mm rms.

In the initial stage of AR operation, the stored current was limited by its short beam life in such a way that the injection rate is equal to the beam loss rate at the maximum current. The short life time was caused by the vacuum pressure rise due to the synchrotron radiation from the beam. As the vacuum condition improved, the maximum stored beam intensity has been increasing. So far the maximum current in the signle bunch mode is 80 mA, which is now limited by the temperature rise in a vacuum component, not by the life time. Although the life time has been improved by a great deal, the typical value is about half an hour for a 10 mA beam and still short compared with the other storage rings.

We have obtained a single bunched beam far above the design intensity in AR, 30 mA. We have been studying beam behavior and especially the beam-cavity interaction which is the most important objective as mentioned before[27]. So far no serious problem has been found in the DAW cavity. Although a longitudinal instability, strong enough to limit the stored current below several miliamperes, is often observed, it can be cured by moving tuners of the caivty carefully. At least in AR, it is possible to find a proper tuner position where every resonant mode in the cavity does not ring with the synchrotron frequency spectrum of the circulating beam. As for the deflecting modes, we have not found any strong instability clearly caused by the caivty. Another vertical coherent oscillation of the beam, however, is observed around 3.7 mA even with the chromaticity correction. It occurs when the accelerating voltage is high and the bunch length is short, and limits the stored current below 4 mA. As the bunch length becomes long, it seems to be very weak. We have known none of the reason.

For quantitative analysis of the stability of a bunched beam, the bunch length is one of the important beam parameters[28]. The measurement was done with a streak camera which detects the synchrotron light emission from the beam[29]. As the beam current increases and exceeds a threshold, bunch lengthening is clearly seen. The bunch lengthening is thought to be caused by a fast longitudinal instbility called the microwave instability which is induced by the mode coupling between two synchrotron modes inside the bunch. The mode coupling theory predicts a threshold current which is in a reasonable agreement with the observed results. Estimation of the impedance was done by a computer program only for the DAW cavities and bellows inserted between vacuum ducts. The theory also shows that the impedance of the bellows is a main cause for the bunch lengthening.

Another interesting subject in the longitudinal direction is a measurement of the higher order mode loss. This result gives us information on the longitudinal impedance. The loss parameter was obtained from the phase shift of the bunch center with respect to the accelerating field. The result roughly agrees with the impedance estimated for AR, that from the cavity and the bellows.

In the transverse direction a betatron tune shift gives us information about the transverse impedance, as the loss parameter does in the longitudinal direction. A preliminary measurement of the tune shift shows that the transverse impedance of the cavities is much smaller than that of the other vacuum ducts, the bellows in particular. This is consistent with the estimated impedance in AR. Large transverse impedance is thought to be a cause for the fast head-tail instability, which limits stored current in large storage rings including the TRISTAN main ring. On the basis of the above result, we planned to insert an inner conductor inside the bellows in the main ring. We expect that the transverse impedance as well as the longitudinal one is reducd by a great deal in the main ring.

A lot of machine time has been devoted to preparation of an internal target system which delivers high energy electrons for the calibration of detectors in physics experiments[13]. We extract gamma ray produced by the collision of the circulating beam at the inserted target, and afterwards convert the gamma ray to electrons. The high energy electron beam is used for the calibration of several thousands of lead glass counters which are calorimeters in two detectors, TOPAZ and VENUS, to be installed in the main ring. The detector groups need two gamma ray lines and also simultaneous production of the gamma ray at the two targets. The two gamma ray lines were prepared by them.

The whole internal target oepration, such as injection, acceleration, extraction and deceleration, is commanded by a computer program. In the normal operation the stored current of about 10 mA is extracted at 5 GeV and the high energy gamma ray to the two lines simultaneously. It takes several minutes to extract the whole current. During the extraction a feedback system works in such a way that each production rate of the gamma ray becomes the desired value. The production rate can be controlled by moving the beam orbit center at each target. We have almost completed the internal target system and obtained satisfactory results.

As stated above, in spring this year a three-cell 500 MHz sueprconducting cavity was temporarily installed in AR for beam tests[15]. The superconducting cavity has extremely high-Q resonacnes, and hence may interact with a circulating beam in a quite different manner from the normal cavity. However, a preliminary beam test showed no such interaction predicted before.

AR IN THE NEAR FUTURE

Now AR is under a long shut down and will be operated again in this Oct. The operation will be continued till the end of this year with the pace of 9 or 8 shifts per week. More than 50 % of the operation time will be devoted to the calibration of lead glass detectors and the rest will be allotted for the start up of the machine, machine study and others. A new experiment using SOR light in AR has been proposed and some work will start soon.

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