# SUPERCONDUCTING RF SYSTEM OF TRISTAN

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## Abstract

Construction of the superconducting RF system of TRISTAN, which consists of 32 5-cell cavities, RF control system and a 6.5 kW He refrigerator, was completed in 1989. They have been operated successfully for colliding beam experiment without serious degradation. This paper describes the present status of operation and operational experiences.

## Introduction

TRISTAN Main Ring (T-MR) started its operation in 1986 with beam energy of 24 GeV using 64 normal conducting 9-cell cavities. The energy was raised up to 28.5 GeV by 1988, by increasing the number of cavities to 104.

Since the R&D work on superconducting cavities convinced us that we could make cavities with good performance, we decided to equip T-MR with superconducting cavities in order to raise the energy further. Construction of 5-cell cavities and a refrigerator system of 4 kW for T-MR started in 1987. Sixteen 5-cell superconducting cavities were installed in T-MR in summer 1988 and we succeeded in accelerating the beam to 30 GeV in Nov.,1988 using these cavities. This was the first large scale application of superconducting RF system to accelerators in the world [1,2,3].

Another sixteen 5-cell superconducting cavities were added in summer 1989. The capacity of the refrigerator was upgraded to 6.5 kW to cope with the increase of the number of cavities. The 32 cavities were cooled down in Oct.,1989 and they provided 200 MV to raise the beam energy up to 32.0 GeV.

## System Description

Figure 1 shows eight cryostats, which contain sixteen cavities, located on one side of the colliding point of Nikko experimental area of T-MR. Other eight cryostats are located on the other side of the colliding point. The details of the cryostat, cavity, RF system and the refrigerator are reported elsewhere [4,5,6,7].

In summer 1989 the capacity of the refrigerator was upgraded to 6.5 kW by adding expansion turbines and compressors. Two high-temperature turbines were added at the same time to reduce the consumption of liquid nitrogen. The 32 cavities were cooled down within four days from room temperature to 4.4 K. The upgraded cryogenic system has been stably operated continuously for more than four months.

Each cryostat is equipped with metal gate valves on both sides. An interlock system closes all the gate valves within 3.5 sec to protect the cavities in case of vacuum accidents. A vacuum unit including 30 l/sec ion pump, cold cathode gauge and Pirani gauge is attached between the gate valves. Turbo-molecular pump units are added to the beam ducts between the cryostats for pumping down the cavity during warming up.

In order to shield the strong synchrotron radiation (SR) from bending magnets, copper SR-masks of 80 mm in diameter and 50 mm in thickness are mounted next to each cryostat. It is expected that, in the case of operation at 32 GeV and 12 mA, incident SR of 120 Watts impinging on a beam pipe in the cryostat is reduced to less than 5 % by these masks.

Figure 1. Eight cryostats including 16 superconducting cavities on one side of the Nikko colliding point of TRISTAN. The other eight cryostats are on the other side of the colliding point.

Present Status of Operation

Table 1 shows a summary of the operation of superconducting cavities for the colliding experiment. The operation of the first 16 cavities started in Nov.,1988 with the average gradient of 4.6 MV/m. In Jan.,1989, one input coupler (#6b) leaked during a cavity aging operation. The leak was so serious that the next cavity in the same cryostat (#6a) was also contaminated too much to operate properly. These cavities were removed from the line and re-treated. After the re-treatment they recovered 10 MV/m in the vertical tests. The leaked cavity (#6b), however, could not exceed 3 MV/m in the horizontal test and has been out of operation by detuning.

Just after the cool down of the 32 cavities in Oct.,1989, a vacuum leak occured in one cavity at an indium seal joint and we removed the cryostat containing this cavity from the line. Without these cavities and the #6b, we started the operation with 29 cavities, which provided 200 MV with the average gradient of 4.7 MV/m and raised the beam energy to 32.0 GeV.

Because one klystron drives four cavities in our system, the field gradient is restricted by the cavity having the lowest Eacc,max in the cavities. Moreover, there is a distribution of external Q from 0.8 to 1.2 x $10^6$, which brings a scatter of the field gradient. Thus the operation field gradient differs from one cavity to another. When the averaged gradient was 4.2 MV/m, for example, the gradient of each cavity distributed from 3.1 MV/m to 6.0 MV/m.

Until Dec.,1989 we had been trying to increase the energy of T-MR as high as possible. This is called the high energy run. Since Feb.,1990, the operation has been aimed at higher luminosity rather than the highest energy, namely the high luminosity run. The beam energy was lowered to 29.0 GeV and the RF voltage of both normal conducting cavities and superconducting cavities were lowered by 15-20% compared with the voltage during the high energy run in order to have an enough margin of accelerating voltage for stable operation.

Beam current has been restricted to 13.5 mA by the unexpected temperature rise in a few N-type connectors of semi-rigid cables which pass the higher-mode power in the vacuum vessel of superconducting cavities. In the summer shutdown of 1990, all the 128 N-type connectors will be replaced by larger size ceramic connectors of 16 mm in diameter and the semi-rigid cables will be replaced with rigid coaxial lines [8].

Figure 2 shows the machine status, cooldown period and number of cavities in operation since the first cooldown of the first 16 cavities. The first 16 cavities have undergone cooldown and warmup five or six times. Total operation time of these cavities at 4.4 K amounts to 9000 hours and they have been operated for the electron positron colliding experiment for more than 5600 hours. The last 16 cavities have been cooled down twice.

Table 1. Summary of the operation of SC Cavities in TRISTAN-MR

| Period | Energy (GeV) | Current (mA) | Number of cav. | Eacc(ave.) (MV/m) | Total Vc (MV) | Physics Run (days) |
|---|---|---|---|---|---|---|
| [High-energy run] | | | | | | |
| Nov'88-Jan'89 | 30.0 | 9 | 16 | 4.4-4.6 | 105-109 | 19 |
| Jan'89-Jun'89 | 30.4 | 8-10 | 14 | 4.0-4.2 | 82-88 | 66 |
| Jun'89-Aug'89 | 30.7 | 9-11 | 16 | 4.4 | 105 | 37 |
| Nov'89-Dec'89 | 32.0 | 8-10 | 29 | 4.6-4.7 | 190-200 | 19 |
| Dec'89 | 31.8 | 9-12 | 28 | 4.3 | 177 | 6 |
| [High-luminosity run] | | | | | | |
| Feb'90- | 29.0 | 8-13 | 30-31 | 3.5 | 160 | 88 |

Total operation time of cavities at 4.4 K -----9000 hours
Total operation time of cavities for the physics run -----5600 hours

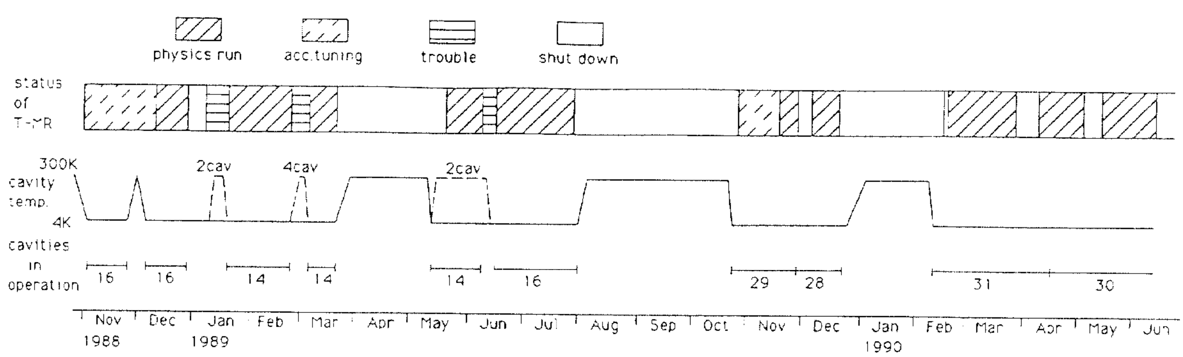


Figure 2. The machine status, cool down period and number of cavities in operation since the first cool down of the fiest 16 cavities.

## Operation experience

### Long-term cavity performance

The performance of the cavities is measured routinely at every shutdown. Figure 3 shows the distribution of Eacc,max measured just after the first cooldown of the first 16 cavities (Nov.1988), just after the first cooldown of the last 16 cavities (Oct.1989) and during the short shutdown in May 1990. Most of them, 26 cavities out of 32, have kept good performance until now. Six cavities, however, have deteriorated to below 5 MV/m. The cavity (#6b), whose Eacc,max degraded to 3 MV/m, that is the lowest value, is just the cavity that had leaked at the input coupler and could not recover after the re-treatment. It should be discussed separately from the long-term performance. Two cavities (#3a,#3b), which are located in the same cryostat, began to degrade suddenly only after one week operation. It is considered to be caused accidentally by dust from somewhere or damaged by discharge at cavity surface. The cavity (#10b) degraded to 4.7 MV/m probably due to discharge at the input coupler.

Results of the measurement of the Eacc,max, Qo and electron loading is reported in detail elsewhere[9].

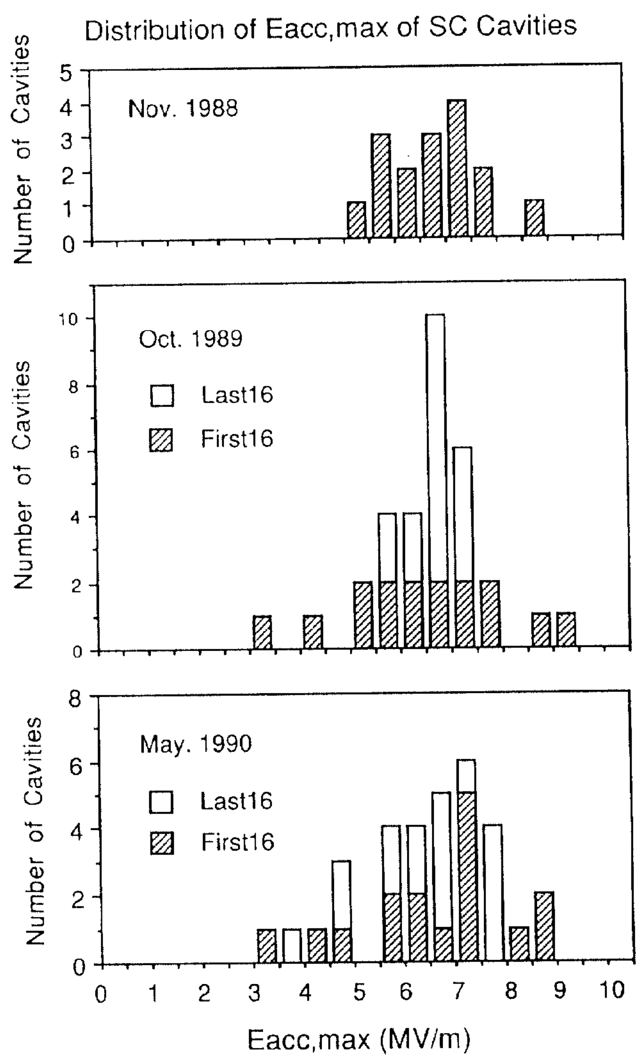


Figure 3. The Eacc,max measured just after the first cool down of the first 16 cavities (Nov.1988), just after the first cool down of the last 16 cavities (Oct.1989) and in May 1990.

### Vacuum environment

Desorbed gas measurement of all cavities during the warmup indicated 1.7-16 mTorr after 60 days operation (Oct'89-Dec'89). This corresponds to the accumulation of 0.5-4.7 monolayers during 60 days operation. Measured gas composition was $H_2$:$H_2O$:CO:$CO_2$ = 34%:22%:27%:17%.

Vacuum pressure in superconducting cavities under the operating condition in T-MR is usually less than $5 \times 10^{-10}$ Torr without beam and $0.5 - 5.0 \times 10^{-9}$ Torr with beam of 10 mA.

Usually cavities are warmed up every two or three months. It is our first experience to operate cavities continuously for more than three months since the last cooldown in Feb.1990. The average vacuum pressure in the cavity section with beam current of 11-12 mA at 29 GeV was about $1 \times 10^{-9}$ Torr in March and rose up to $3 \times 10^{-9}$ Torr in May. It has been getting worse since March. We will continue to watch the change of the pressure until the next warmup in Aug.1990.

### Radiation

Radiation environment was measured at the beam ducts near the cryostat using TLD. Radiation caused by cavities at operation field differs from one cavity to another, from less than 10 R/hour to over 5 kR/hour. Radiation caused by beams ranges from nearly zero to 10 kR/hour (at 1 mA).

Two piezoelectric elements located near the beam pipe were broken due to radiation damage after six-month operation. Pb shielding plates were attached to the piezo elements.

## Conclusion

The superconducting RF system in T-MR has been working successfully for more than one and a half year. It has demonstrated that the large scale superconducting RF system is of practical use for accelerators.

There are, however, some problems to be solved; the degradation of some cavities probably caused by dust contamination, maintaining the reliability in high beam current operation and making the cavities stable in high radiation environment. In a next few years, we will continue to operate T-MR in the high luminosity run scheme and to try to keep stable operation of the superconducting RF system.

## References

1. Y. Kojima et al., "Upgrading of TRISTAN by Superconducting RF System," presented at the IEEE Particle Accelerator Conference, Chicago, U.S.A., Mar. 20-23, 1989, pp. 1789-1791.
2. S. Noguchi et al., "RF Property of the TRISTAN Superconducting Cavities," in Proc. of the 14th Int. Conf. on High Energy Accelerators, Tsukuba, 1989. Particle Accelerators, Vol.29, pp. 17-22, 1990.
3. K. Akai, "Beam Tests and Operation of Superconducting Cavities," in Proc. of the 4th Workshop on RF Superconductivity, KEK, 1989, pp. 189-206.
4. S. Mitsunobu et al., "Cryostat for TRISTAN Superconducting Cavity," ibid.,ref.3, pp. 805-820.
5. K. Saito et al., "R&D of Superconducting Cavities at KEK," ibid.,ref.3, pp. 635-694.
6. K. Akai et al., "RF System for the Superconducting Cavities in TRISTAN Main Ring," ibid.,ref.2, Vol.29, pp. 11-16.
7. K. Hosoyama et al., "Cryogenic System for TRISTAN Superconducting RF Cavity" ibid.,ref.3, pp. 755-763.
8. S. Noguchi et al., "Couplers-Experiences at KEK," ibid., ref.3, pp. 397-412.
9. K. Kubo et al., in this conference.