UPGRADING OF TRISTAN BY SUPERCONDUCTING RF SYSTEM

Y. Kojima, K. Akai, M. Arinaga, K. Asano, E. Ezura, T. Furuya, K. Hara, K. Hosoyama, A. Kabe, E. Kako,
Y. Kojima, K. Kubo, S. Kurokawa, S. Mitsunobu, H. Nakai, T. Nakazato*, S. Noguchi,
T. Ogitsu, K. Saito, Y. Sakamoto, T. Shishido, T. Suzuki,
T. Tajima and T. Takashima

National Laboratory for High Energy Physics
Oho, Tsukuba, Ibaraki 305, Japan

*Laboratory of Nuclear Science, Tohoku University
1-2-1, Mikamine, Sendai 982, Japan

Energy upgrade of TRISTAN by superconducting RF system is progressing. Sixteen five-cell 508 MHz cavities made of niobium have been installed and started to operate in November 1988. Superconducting Cavities have brought up the energy of e^-e^+ to 30.4 GeV from 28.5 GeV with normal conducting RF system. Construction, vertical tests, horizontal tests and operation experience of three months are described.

Introduction

During the early stage of construction, it has become promising that superconducting niobium cavity will be able to work as a real tool.

So the design has been changed and one out of four straight sections of TIRSTAN was left unequipped with normal conducting cavities to provide room for superconducting cavities.

TRISTAN main ring has begun to operate in November 1986 with beam energy of 24 GeV by sixty-four 9-cell normal conducting cavities. Number of cavity was increased year by year up to one-hundred and four cavities as shown in Table I. The table also shows injection and flat-top energy, RF voltage and beam current.

Construction of superconducting RF system[1,2] has started in the spring of 1987, planning to build thirty-two of 5-cell niobium structures. A half of them, sixteen cavities were installed in the tunnel in the summer of 1988, a 4.2 KW helium refrigerator and helium transfer system[3] were also completed at this time. Commissioning of superconducting RF system has started on November 11, 1988 and the first e^+e^- collision at 30 GeV was observed on November 17, 1988. After the year-end shut down, physics run of energy survey from 28.625 to 29.75 GeV took place for about two weeks, then the beam energy was raised up to 30.4 GeV.

Another sixteen 5-cell niobium cavities will be installed in this summer and the beam energy will be upgraded to ~ 32 GeV in the fall of 1989. In this paper we report procedure, performance and some operation experience for the first sixteen cavities.

Procedure and performance

Beam tests at accumulation ring

Before the installation of superconducting RF system in the main ring, beam tests by prototype cavities were performed in the accumulation ring and the major results are shown in Table II.

Table II. Beam tests in the accumulation ring

Period		Cavity	E_{acc}	RF power transferred to beam
May	1984	3-cell	3.5 MV/m	-
July	1984	3-cell	3.7	4 KW
February	1986	5-cell	3	26
October November	1987	5-cell×2	5.4&5.5	68
March	1988	5-cell×2	6.3&7.5	86

By these beam tests, problems which should be concerned for the construction of main ring have been studied and solved. Accelerating field gradient, Q_0, RF power transferred to the beam, frequency tuning, coupling of higher order modes and control system have been found to satisfy the conditions of main ring operation.

Improvement of cavity fabrication

As a result of many year's research and experience on niobium cavities, fabrication process of TRISTAN cavity has been modified from that for the single cells or multicells fabricated in the past. Major modifications which seem to contribute to the improvement of cavity performance are listed below.

- Improvement of niobium material, RRR went up from 110 ~ 120 to 155 ~ 185 during the fabrication period. This has been done by,
  - multiple melting (four times),
  - improved furnace vacuum,
  - slow cool in vacuo after the last melt,
  - raised temperature of melting zone and slowered melting rate,
  - Ti wrapped annealing.

Table I. Progress of beam energy and current with increasing RF

Period		Number of cavities Normal (9-cell)	Super (5-cell)	Beam energy Injection	Flat-top	RF voltage Total	Super	Stored current
October - November	1986	64	0	6.5GeV	24GeV	180MV	0	2mA (2bunches)
December	1986	64	0	6.5	24	180	0	4mA (4bunches)
February - March	1987	64	0	7.0	25	210	0	4.5mA (4bunches)
May - July	1987	84	0	7.4	26	230	0	8mA (4bunches)
October - December	1987	104	0	7.5	27.5	310	0	8mA (4bunches)
January - March	1988	104	0	7.5	28	320	0	13mA (4bunches)
June - July	1988	104	0	8.0	28.5	330	0	13mA (4bunches)
November - December	1988	104	16	8.0	30	410	105~109	10mA (4bunches)
January - February	1989	104	14	8.0	30.4	405	80~88	9mA (4bunches)

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- Intensified check of material surface, by water dipping and thorough visual check, HCl dipping and anodizing if needed.
- Buffing of entire area of half cell after forming, checking by gloss measurement.
- Mechanical grinding of wide area of all EBW seam.
- Careful check of surface with mirror and telescope system.
- Horizontal and rotating electropolish of 5-cell.
- Ti wrapped anneal after the first electropolish.
- Thorough rinsing after the second electropolish, with plenty of water, for extended time, in the ultrasonic bath, with H_2O_2, by monitoring the quality of out-coming water.
- Clean assembling, though not satisfying.

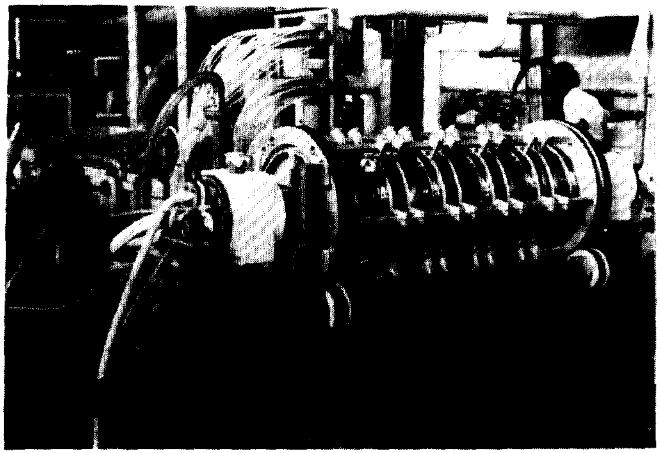

Fig. 1 **Electro-polishing in horizontal position of a rotating cavity.**

In Fig. 1 the horizontal and rotating electro-polishing, in Fig. 2 assembling of a pair of cavities with the horizontal cryostat are shown.

H_2O_2-ultrasonic rinsing was proved to be quite effective, studies of niobium surface[4] with X-ray photo-electron spectroscopy (XPS) and Auger electron spectroscopy (AES) showed H_2O_2 rinsing removes surface contamination such as carbon and nitrogen, forms stable and dense Nb_2O_5 layer of about 30 Å on Nb surface. Fig. 3 shows carbon concentration in the surface region for electropolished sample and for sample which was rinsed by H_2O_2 after the polishing.

Vertical and horizontal tests of cavities

Before assembling in horizontal cryostat, each cavities are tested in a vertical cryostat (vertical test). In these tests followings are measured.

- Q_0 with increasing field for the fundamental mode.
- Field emission electrons and associated X-rays as functions of field strength.
- For $\pi/5$, $2\pi/5$, $3\pi/5$ and $4\pi/5$ modes, Q_0 at several settings of field strength.
- For some bad cavities, temperature mapping with fixed carbon resistor network.

After a pair of 5-cell is assembled in the horizontal cryostat with couplers and frequency tuning mechanism, followings are measured (horizontal tests).

- Loaded Q of fundamental mode, measured values were $0.8 \sim 1.2 \times 10^6$.
- External Q of pick up probe, measured values were $1.3 \sim 5.7 \times 10^{11}$.

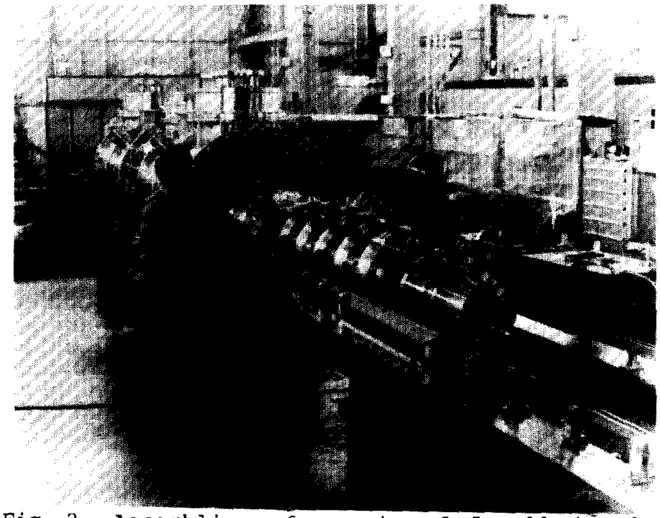

Fig. 2 **Assembling of a pair of 5-cell in the horizontal cryostat.**

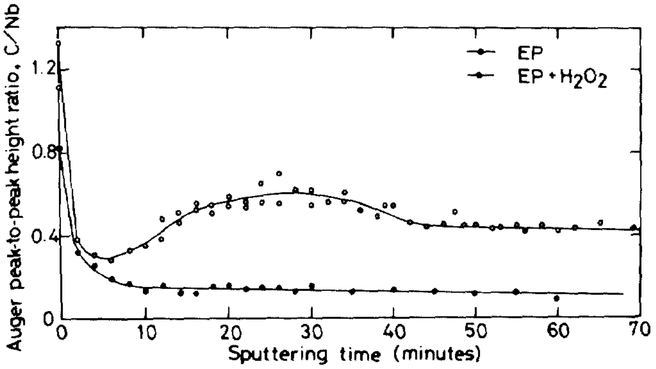

Fig. 3 Auger depth profile of C/Nb, one minute sputter corresponds~one angstrom removal.

- Loaded Q of higher order modes (TM_{011}, TM_{110}, TE_{111}), for TM_{011-0}, $TM_{011-\pi/5}$, $TM_{011-2\pi/5}$ modes with rather higher impedance, values of R/Q times loaded Q are 1 ~ 2 MΩ for these three modes.
- Filtering characteristics of HOM couplers for the fundamental mode, band width of - 50 dB is 700 KHz and external Q for the fundamental mode are larger than 10",
- E_{acc}^{max} and Q_0, average values are about 80 % for E_{acc}^{max} and 70 % for Q_0 compared with the values in the vertical tests.
- Mechanical properties,
  - · frequency at load free; 508.34 ~ 508.51 MHz,
  - · frequency change by length change; 79 ~ 85 KHz/mm,
  - · spring constant; 111 ~ 148 kg/mm,
  - · frequency change by load change; 0.55 ~ 0.74 KHz/kg,
  - · frequency change by helium pressure; - (30 ~ 40) KHz/kgf/cm^2.
- Frequency tuning loop,
  - · stroke of piezo tuner; 5 ~ 7 KHz at 1600 volts,
  - · step response; 20 msec.
- Coupling between two 5-cell,
  - · RF coupling; ~ 0.1 % (field strength)
  - · mechanical; ~ 6 % (axial length)
- Static heat loss of cryostat; averaged value is 28 watts.
- Field emission electrons for some of the cavity.

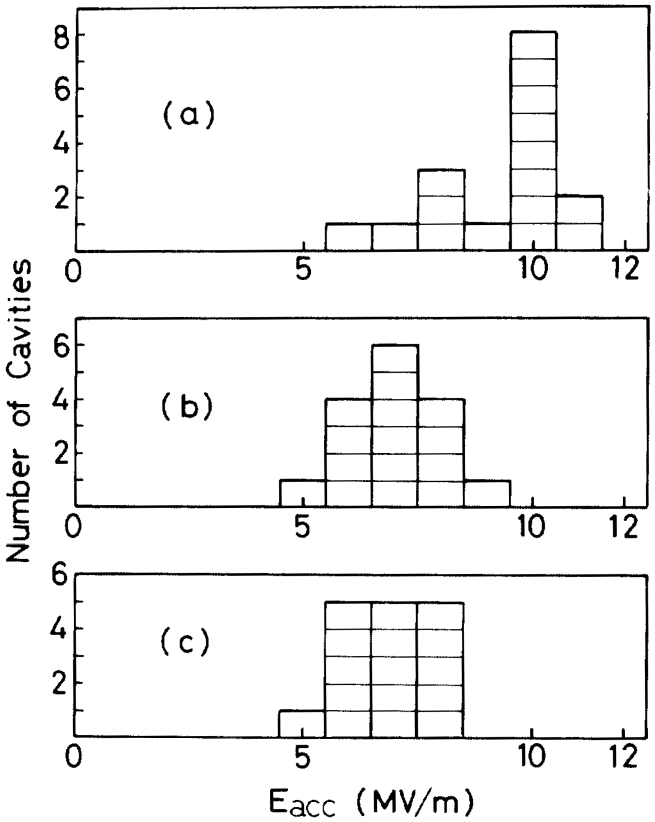

Fig. 4 Distribution of E_{acc}^{max} for sixteen 5-cell at (a) vertical tests, (b) horizontal tests and (c) after two months operation.

Figure 4 shows the distribution of E_{acc}^{max} for sixteen cavities in the vertical and horizontal tests also measured values after two months operation in the tunnel. Q_0 at the horizontal tests and Q_0 at the field of 5 MV/m in the vertical tests are shown in Fig. 5.

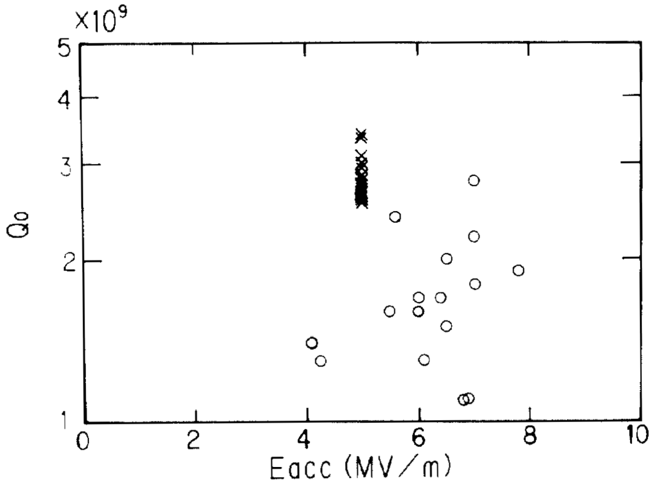

Fig. 5 Q_0 in horizontal tests (circles) and Q_0 at E_{acc} of 5 MV/m in vertical tests (crosses).

Operation experience

Some of the problems we have experienced during about three months operation are described below.

Cryogenic system: Cryogenic system has been running well for more than three months from the first cool down at the end of October 1988. Each cryostat contains 830 liters of 4.4 K liquid helium at the pressure of ~ 1.2 atm. To keep the load of the refrigerator constant, power of heater in the cryostat is controlled automatically to compensate the change of RF losses of cavities during beam injection, acceleration or dumping. This feed back system works nicely and also helps to keep helium pressure change small as 0.01 atm.

To warm one or two cryostats up to room temperature and cool down again, it takes one week. The system needs about 8000 liters of liquid nitrogen per day.

Higher order mode couplers: Soon after the first beam operation, abnormal temperature rise was found on some semi-rigid coaxial cable which connects two ceramic feed throughs one at the exit of HOM coupler and the another at the outmost wall of the cryostat. This problem is at present the reason of upper limit of the beam current.

Bad contact of the inner conductor of the connectors and larger attenuation of HOM in the semi-rigid cable are the reasons of heating. Modification of the inner conductor of the connectors and improvement of cooling of the cable are scheduled during the spring shut down.

Input couplers: Two ceramic windows of input couplers have caused leaking and had to be replaced, probably due to RF arcing. All input couplers have been tested before assembling to the cavity, with transmission RF mode up to 180 ~ 200 KW, then tested with cavity but with entire reflection mode at room temperature to ~ 80 KW.

New type of windows with TiN coated ceramic and with arc sensor will be adopted on the last eight cavities.

Degradation of E_{acc}^{max}: E_{acc}^{max} was almost kept at the same value in average from the horizontal tests to the beginning of January 1989. But slight decreases of E_{acc}^{max} are found on two cavities, the phenomena should be studied further.

Synchrotron radiation: On the flange of gate valves at the end of cryostat, X-ray from synchrotron radiation are measured with cobalt-glass and the strongest value is 1×10^6 R/day . The source of the X-ray is not able to be decided at the moment but the effect of this strong X-ray on niobium cavities should be watched.

Acknowledgements

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