Long Term Performance of the TRISTAN Superconducting RF Cavities

E. Kako, K. Akai, T. Furuya, K. Kubo, S. Mitsunobu, H. Nakai, S. Noguchi, T. Shishido, T. Tajima and T. Takahashi
KEK, National Laboratory for High Energy Physics
Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

TRISTAN was operated with an average beam current of 12.0 mA at a beam energy of 29.0 GeV in 1990. The thirty-two 5-cell superconducting rf cavities had been kept cold for about 6 months. No irrecoverable degradation of the cavity performance had been observed in the long term operation. Changes of the cavity performance, troubles and improvements of the superconducting rf system are described in this paper.

I. INTRODUCTION

Construction of the superconducting rf accelerating system was started in 1987. The first 16 superconducting cavities were installed in the TRISTAN main ring in the summer of 1988 and the last 16 cavities were installed in the summer of 1989. The superconducting rf system consisting of 32 units of 508 MHz 5-cell niobium cavities were completed in the autumn of 1989 and they were cooled down at 4.4K by the 6.5 kW Helium refrigerator system. The detailed description about this system has already been reported in references [1-3].

The beam energy marked the highest value of 32.0 GeV in late 1989 with the additional accelerating voltage (200MV) generated by the superconducting cavities. After the highest energy run, the beam energy had been lowered to 29.0 GeV in order to attain the stable operation with the higher beam current for a high luminosity run. Though the beam current was increased up to 14.0 mA, the maximum beam current in the physics run was limited to 13.5 mA by the heating-up of N-type ceramic connectors used for extracting higher order mode (HOM) power [4-5].

In the high luminosity run, the superconducting cavities had been kept cold for about 6 months from February to July in 1990. The changes of the cavity performance in the long term operation had been measured routinely whenever the beam in the ring was turned off for the maintenance of TRISTAN. The changes of the maximum accelerating gradient (Eacc,max), the unloaded Q value (Q_0), the field enhancement factor (β) and the vacuum pressure in the superconducting cavity are presented in the later section.

The connectors and coaxial cables used for the HOM couplers were replaced in the autumn of 1990 with the new type ones whose pin contacts were improved. In the present operation started in January 1991, the current limit will be increased to more than 20.0 mA.

In this coming summer shut-down, there is a program to replace the cavities which had suffered from a degradation in the ring with newly fabricated cavities which have proven to have superior performance. Two cryostats including 4 cavities are being prepared. The results of the vertical and horizontal tests of these spare cavities are also presented.

II. CHANGE OF CAVITY PERFORMANCE

Distributions of the maximum accelerating gradient of the superconducting cavities are shown in Fig. 1. One cavity has not been operated since its installation into the main ring due to a low Eacc,max (see, Table 1.(1)). Two cavities (A and B) in the same cryostat had suddenly degraded in the early stage of operation and have not recovered since that time. At the

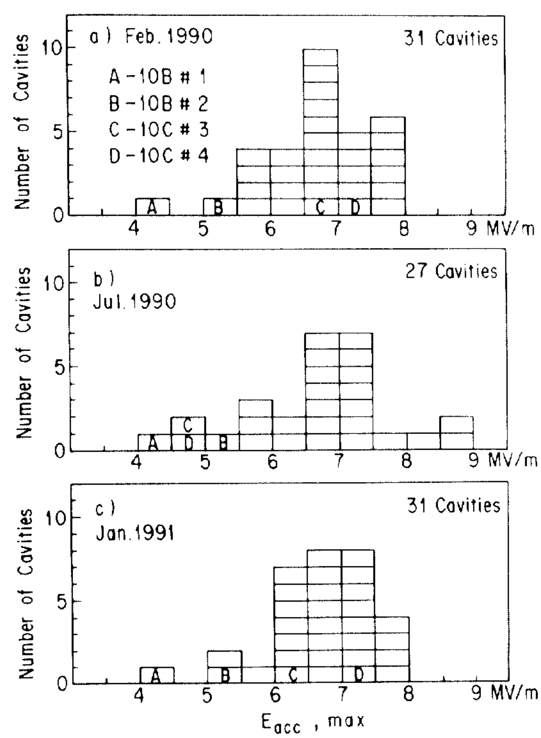

Fig. 1 History of distribution of Eacc,max of superconducting cavities.
(a) beginning of the long term operation (February,1990),
(b) end of the long term operation (July,1990),
(c) beginning of the present operation after warming up (January,1991).

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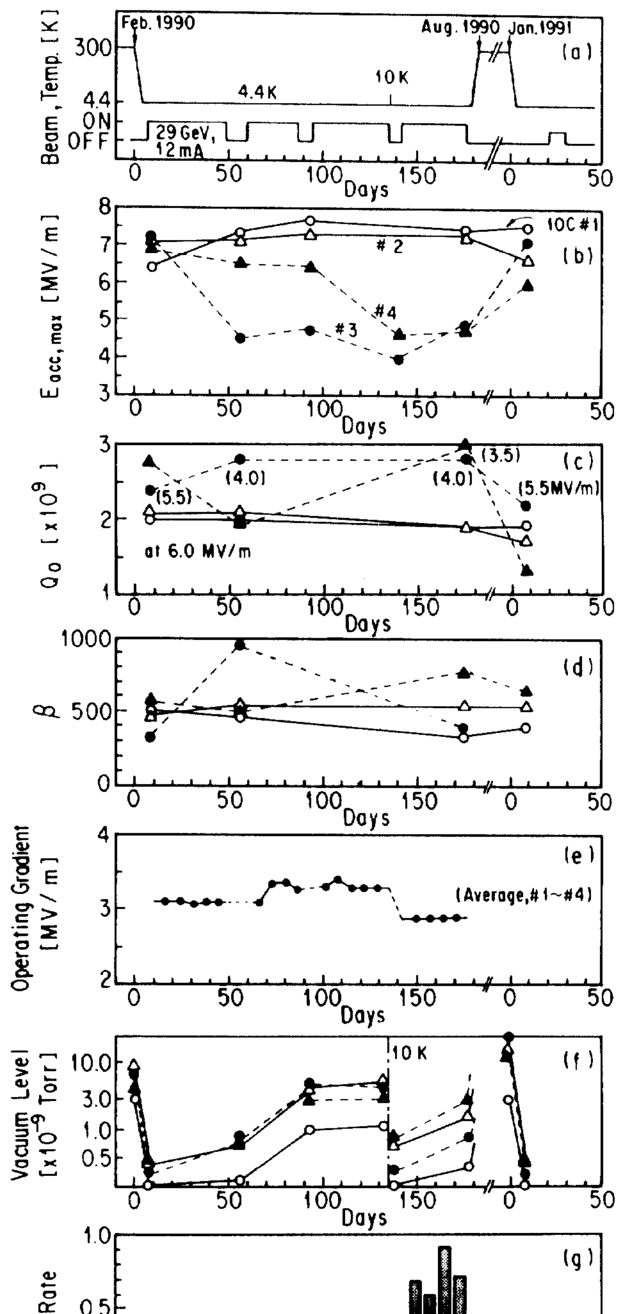

Fig. 2 Time variation of the cavity performance for four cavities driven by one klystron. (10C #1,#2,#3 and #4).
(a) temperature and beam-on,off status,
(b) maximum accelerating gradient (Eacc,max),
(c) unloaded Q value (Q_0) at 6.0 MV/m if not specified,
(d) field enhancement factor (β),
(e) operating gradient,
(f) vacuum pressure in the cavity measured by the cold cathode gauge at beam-off,
(g) average trip rate of the 4 cavities per one physics run.

beginning of the long term operation (Fig. 1(a)), 29 cavities among the 31 operating cavities had an Eacc,max greater than 5.5 MV/m. In the middle of the long term operation, four cavities (10D#1~#4) driven by one klystron had been put out of operation due to repair of the troubled input coupler (see, Table 1.(4)) and so frequent trip of two cavities. As shown in Fig. 1(b), 25 cavities had kept the values of the Eacc,max for 6 months. Two cavities (C and D) in the same cryostat, however, had degraded in Eacc,max in their long term operation. We think this was due to adsorbed gasses onto the inner surface of the cavity, since warming up to room temperature made their Eacc,max recover (Fig. 1(c)).

Figure 2 shows the time variation of the cavity performance for 4 cavities including C and D cavities in Fig.1. The values of Eacc,max, Q_0 and β of 10C#1 and #2 cavities in the same cryostat had not changed for the long term operation at all. In contrast to these cavities, the Eacc,max of 10C#3(C) and #4(D) cavites had gradually deteriorated as the days of the operation passed. The correlation of the deterioration of the Eacc,max with the change of Q_0 and β is not clear in this case. The vacuum pressure in the cavities had gotten worse with the days. The cavities accidentally warmed up to 10K due to a trouble of the refrigerator system on the 135th day. Although the vacuum pressure was recovered by desorbing the adsorbed gass (H_2), the Eacc,max of the cavities remained in a deteriorated state at that time. Finally, the Eacc,max recovered completely after warming up to room temperature as seen in Fig. 2(b).

The trip rate of the cavities had increased remarkably after 100 days, in spite of the low operating gradient compared with the Eacc,max. The problem of the frequent trip will be reported in detail in reference [6].

III. HOM EXTRACTION SYSTEM

An abnormal heating of the N-type ceramic connectors and cables occured due to a loose pin contact and a poor conduction of heat. A tightening of the pin contact and a water cooling near the connector were performed. However, when the beam current reached to 14.0 mA, one connector was unfortunately burnt. Measured HOM power extracted by a coupler amounted to 150 W at 4 x 3.5 mA, in which 77% consisted of the component less than 1.0 GHz (mainly TM_{011}-modes).

A newly developed HOM extraction system is shown in Fig. 3. Double ceramic disks (3.5 mm in thickness and 23 mm in outer diameter) in two connectors divide an atmosphere into a cavity vacuum, an insulation vacuum and air. The diameters of the inner and outer conductors located in a straight coaxial line are 7.0 mm and 16.1 mm, respectively. From the results of the bench test, the allowable rf power level passing through this system is guaranteed more than 600 W at 0.9 GHz under no cooling condition.

Replacement of the connectors had been carried out in the main ring tunnel by using simple clean booths. Because the end plates of the vacuum vessels had to be removed, the cavities had been N_2 leaked on three occasions. No deterioration relating to this work was found as seen in Fig. 1(c).

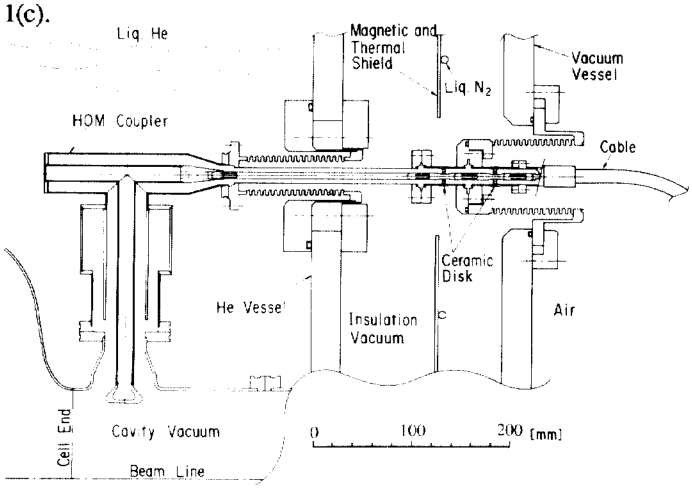

Fig. 3 A newly developed higher order mode extraction system.

IV. TROUBLES OF INPUT COUPLERS

In general, input couplers are tested as follows;

1. up to 200 kW under matching conditions at the test stand,
2. up to 75 kW under total reflection conditions and at room temperature after assembling to the cavity.

Up to the present, 57 input couplers have been made and tested. No trouble has occured at the test stand since arcing detectors had been employed [4,5,7].

Troubles with the ceramic windows which occured in the main ring are summarized in Table 1. In three cases with minute pin-hole leaks, cavity performances were recovered by only the replacement of the input couplers. The other two cavities, however, have not been operated with the beam. They will be replaced with new cavities at the next long shut-down. Their inner surfaces will be retreated by electro-polishing in order to restore the performance.

Table 1.
Summary of ceramic window leak of input coupler.

Cavity	Day	Temp.	Status	Damage of window
(1) 11B#3,	Jan.1989,	4.4K,	aging at beam-off,	crack.
---- detuned because of low Eacc,max (OK in the vertical test after retreatment, but 3.0 MV/m in the horizontal test).				
(2) 10B#1,	Feb.1989,	4.4K,	rf recovery with beam,	pin-hole.
---- OK after replacement of input couper.				
(3) 10B#1,	Oct.1989,	300K,	shut-down,	pin-hole.
---- OK after replacement of input coupler.				
(4) 10D#2,	Jun.1990,	4.4K,	aging at beam-off,	burnt PE-disk.
---- OK after replacement of input coupler.				
(5) 10C#3,	Jan.1991,	4.4K,	aging at beam-off,	crack.
---- detuned because of a serious arcing of coaxial parts.				

V. SPARE CAVITES

Four cavities have been fabricated by the same method as the cavities which are being operated in the main ring [8]. All of them achieved an Eacc,max of more than 9.0 MV/m in the vertical tests. One cavity (18b) among these four recorded the highest value (15.0 MV/m) of the Eacc,max as shown in Fig.4 [9]. It was not limited by field emitted electrons, but an available rf power. The problem that the cavity performance degrades after the assembly to the horizontal cryostat still remains as follows. In the horizontal tests, one cavity (17b) showed heavy field emissions, low Q_0 values at relatively low field and low Eacc,max of 3.1 MV/m in spite of good performance in the vertical test.

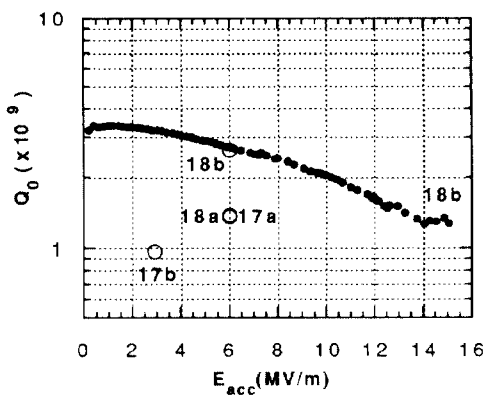

Fig. 4 Qo-Eacc plots of the spare cavities in the vertical (●) and horizontal (O) tests.

VI. ACKNOWLEDGEMENTS

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