Operational Experience with the TRISTAN Superconducting RF System

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Abstract

The superconducting RF system including thirty-two 5-cell cavities has been operated in TRISTAN for three years. This paper describes cavity performance in the ring, study of frequent trips caused by a discharge in the cavity and the way we cured some troubles.

I. INTRODUCTION

The superconducting RF system has been operated in TRISTAN Main Ring for physics experiments since the autumn of 1988. In the first phase of the operation aiming at the high energy until Dec. 1989, the cavities had been operated with the average gradient of 4.4-4.7 MV/m for one and a half years. The beam energy was raised up to 32.0 GeV using 29 superconducting 5-cell cavities with the total accelerating voltage of 200 MV and 104 normal conducting 9-cell cavities with 320 MV. In the second phase of the operation aiming at the high luminosity since Feb. 1990, the beam energy has been fixed at 29.0 GeV and the average gradient was lowered to 3.5 MV/m because we attached greater importance to stable operation for the large beam current than the higher gradient [1]. For the total period of three years, the first installed 16 cavities have been kept cold for more than 10,000 hours and operated for 270 days of physics experiment.

II. CAVITY PERFORMANCE IN THE RING

A. Vacuum Pressure

Until 1989 every cavity had been warmed up every two or three months. In 1990, however, the cavities have been kept cold for six months. Although each cavity has an ion pump of 30 l/s, the cavity itself acts as a powerful cryo pump, so that a large amount of gas adsorption at the cavity surface is expected in the long range of operation.

Fig. 1 shows a change of vacuum pressure in each cavity during the six months of the continuous operation as a function of the location. The cavities are located in a straight section between two arcs. The interaction region divides it into two cavity sections. All data were taken when beams of 11-13 mA were accelerated to 29 GeV. At the beginning of the run (Mar.1990), the vacuum pressure in the cavity near the interaction region or near the arc sections was about 1 x 10^{-9} Torr, while in other cavities less than 5 x 10^{-10} Torr. After two months operation (22Apr.) it became worse to 3 x 10^{-9} Torr in the cavities near the arc sections and near the interaction region. After four months operation (16Jun.) it became worse to 3 x 10^{-9} Torr in almost all cavities. This indicates that the gas from the arc sections and the interaction region was adsorbed in the nearest cavities at the beginning and then the vacuum pressure rise extended gradually into further cavities. In a short shut down in June an accident happened that compressors of the refrigerator stopped. All the cavities were warmed up to between 7 and 20 K. Most of hydrogen gas that had been adsorbed at the cavity surface was desorbed and pumped out. The vacuum pressure in the cavities recovered to the original level at the begining of the operation.

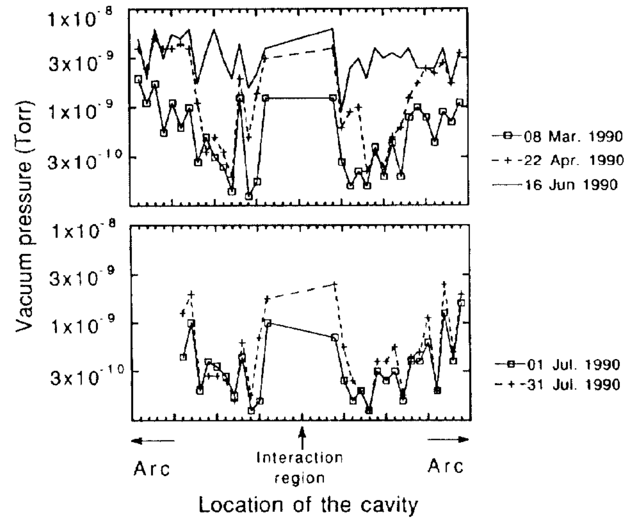

Figure 1. The change of vacuum pressure in each cavity as a function of the location during six months of operation: (a) before and (b) after the warm up to 7-20 K.

B. The Maximum Accelerating Gradient

The cavities have undergone 3 to 6 times of cool down and warm up in the past 2 or 3 years. In addition, most of them experienced once unexpected warm up to 20 K, as was mentioned above. Cavity performance such as the maximum accelerating gradient (Eacc, max), the Q value and the electron loading has been measured at every shut down of the machine.

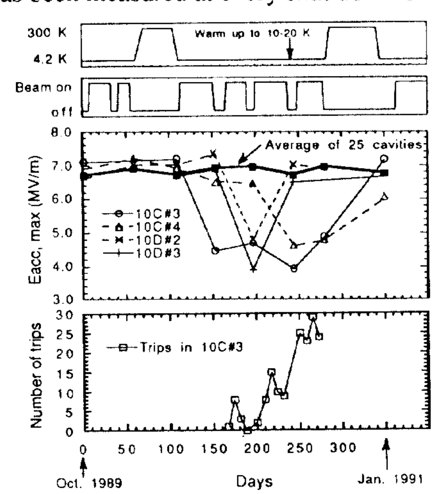

Figure 2. The change of the maximum accelerating gradient.

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Fig. 2 shows the change of Eacc, max of 29 cavities as a function of days. The results are summarized as follows.

(1) Most of the cavities, 25 cavities among 32, show no clear degradation during the long term operation and under several times of cool down and warm up. The average Eacc, max of them has been kept between 6.7 to 7.0 MV/m.

(2) The Eacc, max of four cavities (10C#3, 10C#4, 10D#2 and 10D#3) once decreased, but after warm up to the room temperature or even to 20 K they recovered to the previous values. The temporary degradation of these cavities is closely related with frequent interlock actions, as will be discussed afterwards.

(3) Three cavities (10B#1, 10B#2 and 11C#3) degraded and have not recovered. Two of them are still used in the operation with lower gradient of 2.5 or 3.0 MV/m. One is detuned and out of operation. The performance of those cavities shows no clear dependence on the cool down and warm up. Details of the measurement are reported in [2,3].

III. INTERLOCK ACTIONS

Important interlocks installed in the RF system to protect the cavities are quench detectors, arc sensors for the input couplers, sensors for the cavity vacuum and pressure gauge of liquid Herium [4]. When some interlock action works, the RF switch for the klystron which drives the tripped cavity is shut off. Frequent interlock actions are undesirable because they sometimes cause shorter lifetime of the stored beam, more background noise at detectors of physics experiments or beam loss in the worst case.

Fig. 3 shows typical examples of characteristic feature observed when the trip occured. The pick up signal falls down to almost zero within a very short time of less than 10 μs, that is much shorter than the filling time of the cavity taking account of the beam loading (600 μs without beam and 300 μs with 10 mA). The fast decay is also observed in the signal of the fundamental mode from HOM couplers. Thus the stored energy in the cavity decays with the same time constant. The reflection power from the cavity also changes at the same time. A sharp spike signal is sometimes observed in the fundamental mode from HOM couplers.

Fig. 4 shows the average number of interlock actions for each cavity in one beam colliding experiment (for about 2 hours). Most of the interlock actions are classified into two types. One type of them is a trip which occurs during the beam acceleration from 8 GeV to the maximum energy. More than 50 % of all interlock actions are this type. The other type of them occurs at the maximum energy.

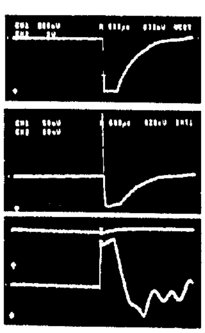

Figure 3. Characteristic feature of the trip in the cavity. (5msec /full scale)

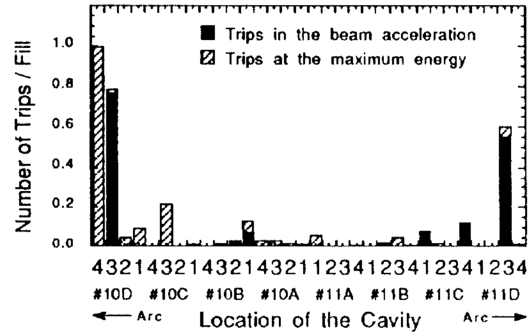

Figure 4. The average number of interlock actions of each cavity in one beam filling from 8 Apr. to 31 Jul. in 1990. That of 10D#4 is until 16 Apr.

A. Trips during the Beam Acceleration

The most distinctive feature of the trip during the beam acceleration is a large amount of sudden gas burst to nearly 10^{-7} Torr. During the acceleration, the accelerating field in the cavity is raised slowly from 1 MV/m to 3 - 5 MV/m in 4 minutes. Fig. 5 shows the occurrence of the trip as a function of the accelerating field. It is seen clearly that the trip occurs at special field levels around 1.5 and 2.2 MV/m, those voltages being common for the cavities in which this trip occurs.

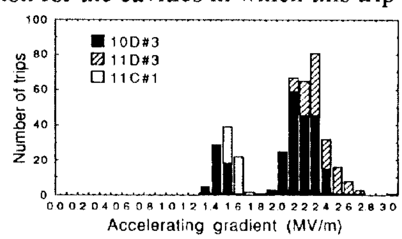

Figure 5. The number of trips during the beam acceleration from Apr. to Jun. in 1990 as a function of the field.

In bench tests and in RF aging before the operation for physics experiments in the ring, two side multipactings at capasitive gaps of HOM couplers are observed in the field level from 0.3 to 0.8 MV/m with vacuum pressure rise, change of output power from HOM couplers and heat pulses of carbon thermometers on HOM couplers. This multipacting is processed in half an hour [5]. In the case of the trip during the beam acceleration, since we always use cavities more than 1 MV/m, the observed field level when the trip occurs is more than 1 MV/m. Nevertheless, we found that when the trip rate became high, the multipacting at HOM couplers from 0.3 to 0.8 MV/m was also observed by lowering the field. Fig. 6 shows the change of the trip rate as a function of time. RF processing for the multipacting at HOM couplers was performed sometimes, marked by "HOM" in the figure. After the processing, the trip rate was reduced to nearly zero for several days. These observations strongly indicate that the trip is related to the multipacting at HOM couplers.

Next we discuss the trip with respect to radiation. As shown in Fig. 4, most of the trips during the acceleration occur in two cavities which are located in the colliding side of two cryostats nearest to each arc section. Every cryostat has a mask at the bending side of it to prevent synchrotron radiation from the arc section. Although the direct radiation can not hit the cavity surface, a part of them hit the beam pipe of the colliding side of the cryostat. In order to study the effect of masks on occurrence of the trip, we moved the masks toward the center of the ring by 1 mm on 7 May 1990. The trip rate in the cavity of 11D#3 reduced drastically after the mask was moved, as is shown in Fig. 6. As for the cavity of 10D#3, no clear change is seen by the movement of the mask. The reason for the difference between 11D#3 and 10D#3 is considered as follows. The location of the masks were measured accurately, which showed that before the movement of the masks, the mask of 11D#3 and that of 10D#3 had been located +0.5 mm and -0.5 mm, respectively. (the plus sign means the direction toward the ring center) After the masks were moved by 1 mm, the location of the mask of 11D#3 was +1.5 mm, while that of 10D#3 only +0.5 mm. Consequently the mask of 11D#3 effectively cut the radiation from the arc after the mask was moved and that of 10D#3, on the other hand, could not cut it effectively. Furthermore, the trip is related to the direction of the beam circulation. When only electron beams were accelerated, 10D#3 tripped but 11D#3 never did. When only positron beams were accelerated, 10D#3 never tripped but 11D#3 did. These observations indicate that the trip is triggered by the synchrotron radiation of the beam.

We conclude that the trip in the beam acceleration is a discharge in the cavity caused by multipactings in HOM couplers triggered by radiation. We will be able to reduce the occurrence of the trip by adjusting the masks and by RF processing.

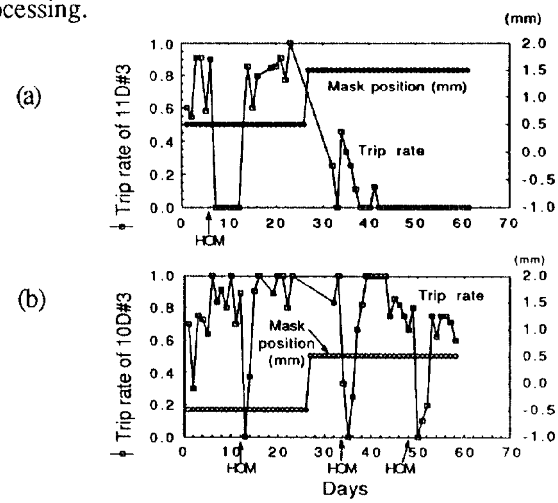

Figure 6. The change of the trip rate as a function of time in (a) the cavity of 11D#3 and (b) the cavity of 10D#3. "HOM" indicates RF processing for HOM couplers.

B. Trips at the Maximum Energy

Trips at the maximum energy (29 GeV) have concentrated on some cavities. They were detected either by the arc at the input couplers, the break down of the cavity, gas burst or abnormal cavity field. Although some of them reached higher gradient as high as 7 MV/m without beams, they tripped at lower gradient with a large current of beams. A cavity of 10D#4 was detuned to be out of operation in Apr. 1990 because the trip rate of it increased intensively, although the Eacc, max and the Q value of it have not decreased.

We recognized that the trips in some cavities had relevance to some bad conditions of the cavities. During two months when we had a problem in polyethylene disks of input couplers, which is mentioned later, we had frequent trips due to the arc in the input couplers of 10D#1 and 10D#2. As for the trip in 10C#3, it is considered to be due to some bad condition at the input coupler.

C. Correlation between the Trip and the Cavity Performance

There is a correlation between some of the frequently tripped cavities and the decrease of the Eacc, max of four cavities shown in Fig. 2. The decrease of the Eacc, max of 10D#3 and 10D#2 is considered to be caused by a large amount of gas burst of the trip of 10D#3 during the beam acceleration. Although 10D#2 itself had no trip during the beam acceleration, a large amount of gas reached to it when 10D#3 tripped since both cavities are connected to each other by a warm vacuum duct. The trip rate of 10C#3 remarkably increased in the period when its Eacc, max was low. Although 10C#4 had seldom tripped with its own reason, it was observed that the trip of 10C#3, which is located in the same cryostat as 10C#4, caused abnormal state also in 10C#4 such as the gas burst and the fast decay of the field. The degradation of the Eacc, max of these four cavities are thus related with the frequent trips. As is mentioned before, the degradation of these cavities recovered after the warm up.

IV. Troubles and Cures

Some connectors and cables in vacuum vessels to extract HOM power were burnt in the early stage of the operation. During the operation in 1990 we had restricted the beam current to less than 13.5 mA to avoid this trouble. In the summer of 1990 the HOM extraction system was improved using larger ceramic connectors. This system is expected to be safe with over the 20 mA of beam current.

Each input coupler has two disks: one is a ceramic window to divide the cavity vacuum from atmosphere and the other is a disk made from Teflon or polyethylene located on the atmospheric side of the ceramic window. Two polyethylene disks were burnt down seriously, one of which caused leakage of the ceramic window. Logged data indicate that the burning advanced gradually for two months. Some other troubles in ceramic windows will be reported in reference [3].

Piezoelectric transducers are located outside the cryostats to tune the cavity. Five of them failed. Plastic bolts to stack the piezoelectric elements were broken probably due to radiation damage [6]. All the piezoelectric tuners were replaced by new type ones using SUS bolts with springs.

V. References

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[6] S. Mitsunobu, private communication.