THERMAL CYCLE TESTS OF KEK 500MHz CAVITIES

T. Furuya, S. Mitsunobu, T. Tajima and T. Takahashi

National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

ABSTRACT

This report gives the results of thermal cycle tests of two 500MHz Nb cavities at KEK. A single cell test cavity (RRR130) has kept its performance of Q_0 and $E_{acc/max}$ during two thermal cycles of 130K x 20 hours and 160K x 33 hours. A 5-cell TRISTAN cavity (RRR200) which was warmed up to 115K in 14 hours also showed no degradation of Q_0 and $E_{acc/max}$. In both cases, no change of cavity performance was observed.

1. INTRODUCTION

Recently, Q degradation of superconducting Nb cavities has been reported from several laboratories in the world[1,2,3,4]. The degradation has been observed on the cavity made from high purity Nb which is cooled down under slow cooling condition or kept at around LN_2 temperature for several hours, it seems to be a serious problem for practical use of superconducting cavities in particle accelerators. To avoid such a degradation, cavities have to be cooled across the LN_2 temperature at a fast cooling rate, but there may be a risk of cryogenic and vacuum accidents in the system. Moreover, cavities have to be warmed up to room temperature once to recover the Q value, it means a waste of time in the physics run.

In KEK, thirty-two 5-cell Nb cavities were fabricated and have been operated successfully since the summer in 1989[5,6]. In our system, it was experienced that a large amount of residual gases were condensed on the cavity surface during the operation period and it gave rise to RF-trip due to discharging in the cavity[7]. After the operation for three months, for example, we tried warming the cavities to room temperature under turning off the vacuum pumps, and found that the pressure of the cavities placed at both ends of the cavity section reached 20mTorr. To reduce such condensed gases, warming up the cavity periodically to around LN_2 temperature seems to be effective.

For these reasons we attempted to know the effects of a thermal cycle to our cavities. First of all, two thermal cycles were made to a single cell test cavity and then one cycle was given to a TRISTAN 5-cell cavity.

2. SINGLE-CELL TEST CAVITY

A prototype single-cell cavity was used for the thermal cycle measurement. The cavity has the same shape as the center cell of the TRISTAN 5-cell cavities and was fabricated in the same procedure as them. The RRR of Nb sheets is 130, which is the same grade as that of earlier cavities for TRISTAN[8].

History of Surface Treatments

This single-cell test cavity was built for the establishment of the fabrication procedure of thirty-two TRISTAN cavities and has been electropolished four times for various measurements and removed the surface by 105μm up to now. The surface treatments performed to the cavity are summarized in Table 1.

After welded, the cavity was electropolished by the horizontal rotation electropolishing system[9] and removed the surface by 80μm. In the polishing system, the acid mixture of HF and H_2SO_4 is circulated between an enclosed cavity and an acid reservoir, therefore the cavity surface is exposed to the hydrogen-rich circumstances. During the removal of 80μm, the surface of the test cavity was exposed to the acid mixture for 270min. To reduce hydrogen contaminants in the Nb, the cavity was annealed in a vacuum furnace at 700℃ for 90min.

Slight electropolishing processes were repeated to the cavity after the annealing and removed the surface by 25μm in total, and no additional annealing process has been made. During these electropolishing, the surface has been exposed to the acid mixture for 210min.

Table 1: Surface Treatments of a Single-cell Test Cavity

Material	RRR 130	
History of Surface Treatment	Electropolishing	80μm
	Vacuum annealing	700℃ x 90min.
	Electropolishing	5μm
		10μm
		10μm
	Baking under Vacuum Pumping	120℃ x 10hours

Thermal Cycle

Two thermal cycle tests were performed successively to the cavity as shown in Fig.1. At the first cooldown the cavity was pre-cooled with LN_2 and reached 80K in 80min. After keeping at 80K-100K for 14hours, the cavity was cooled down to 4.2K and measured(Measurement A).

After the measurement A, the cavity was warmed up to 130K in 20hours and cooled again(Measurement B). In the last cycle the cavity was warmed up to 160K in 33hours and measured(Measurement C).

During these thermal cycles, the temperature of the cavity was measured with three thermocouple thermometers (PKvsAu7Fe) fixed on the outer wall of both beam pipes and the equator of the cavity. The difference of the temperature at these positions were within 10K during the warming up processes.

Table 2: Summary of Thermal Cycles for a Single-cell Test Cavity

Cooldown	300K - 80K	80min.
	80K - 100K	14hours
	100K - 4.2K	50min.
Measurement A		
	4.2K - 100K	14hours
	100K - 130K	6hours
	130K - 4.2K	50min.
Measurement B		
	4.2K - 100K	12hours
	100K - 160K	21hours
	160K - 4.2K	50min.
Measurement C		

Results

The Q values obtained at each thermal cycle are shown in Fig.2. No degradation of Q_0 and $E_{acc/max}$ was observed. The field gradient was limited by field emission in every cycle and the strength of X-ray observed with NaI also showed no difference. The Q value at low field gradient was 3.5×10^9, which corresponded to the surface resistance of 77nΩ .

3. TRISTAN 5-CELL CAVITY

Four 5-cell cavities were fabricated as the spare modules of the TRISTAN superconducting cavity system. One of them (MR-18a) was made from Nb sheets of RRR 200. This figure is higher than that of the other cavities for TRISTAN. The RRR of the sheets used for half cells are distributed as shown in Fig.3. At the first vertical test, a thermal cycle test was performed to the cavity.

Surface Treatments

The cavity was fabricated in the KEK standard procedure; that is, electropolishing, annealing, additional electropolishing, H_2O_2 rinsing and thorough rinsing with a large amount of pure water. The surface of the cavity was exposed to the acid mixture for 270min. and 70min. before and after annealing respectively.

Table 3: Surface Treatments of MR-18a

Electropolishing	80μ m
Annealing	700℃ x90min.
Electropolishing	10μ m
	pure water rinsing
	H_2O_2 rinsing
	ultra-pure water rinsing
Baking under vacuum pumping	120℃ x10hours

Thermal Cycle

The thermal cycle given to the cavity is summarized in Table 4 and Fig.4. The cavity was pre-cooled to 80K in 18hours. After the 1st measurement, the cavity was warmed up to 115K in 14hours and cooled again. Three thermocouple thermometers were used to monitor the temperature of the cavity, which were fixed on the outer wall of upper(UP) and bottom(BOTTOM) beam pipes and the equator of the center cell.

Results

As shown in Fig.5(a)-(b), no degradation of the Q value was observed. The Q value at low field gradient was 3.2×10^9 which was equivalent to the surface resistance of 84nΩ . Though the improvement of $E_{acc/max}$ due to RF processing was observed after the cycle, heating at the cell neighboring to the center cell limited the field gradient in both cases and the heating position did not move even after the thermal cycle.

Table 4: Thermal Cycle of MR-18a

Cooldown	300K - 80K	18hours
	80K - 4.2K	1hour
1st Measurement		
	4.2K - 115K	14hours
	115K - 4.2K	1hour
2nd Measurement		

4.CONCLUSION

The Q degradation due to warming up to around LN_2 temperature was not observed on both a single-cell test cavity and a 5-cell cavity(MR-18a). Temperature mapping and X-ray measurements also showed no change of cavity performance. The Q values at low field gradient of the single cell cavity and the 5-cell cavity were 3.5×10^9 and 3.2×10^9 even after the thermal cycle, which corresponded to the surface resistance of 77nΩ and 84nΩ , respectively.

Furthermore, the cavities operated in TRISTAN have been cooled down several times up to now at the slow cooling rate of about 7K/hour, that is, 31hours from room temperature to 80K and 51hours to 4.4K[10]. But no cavity has shown the degradation of Q value due to this slow cooling condition. In our case, i.e. using Nb sheets of RRR<200, electropolishing, annealing at 700℃ , H_2O_2 rinsing and baking at 120℃ , no evidence of the Q degradation has been observed.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Y. Kimura and Prof. S. Kurokawa for their continuous encouragements and to thank all the members of the superconducting cavity group for continuous support and helpful discussions.

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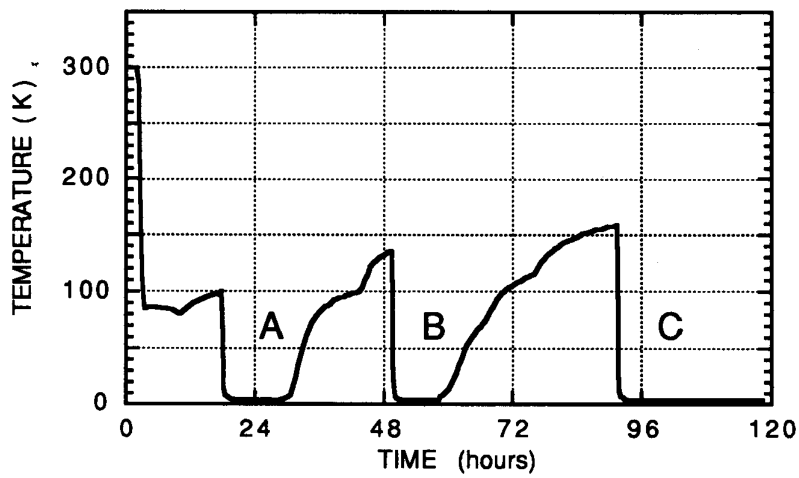

Fig. 1 Thermal Cycle of Single Cell Test Cavity

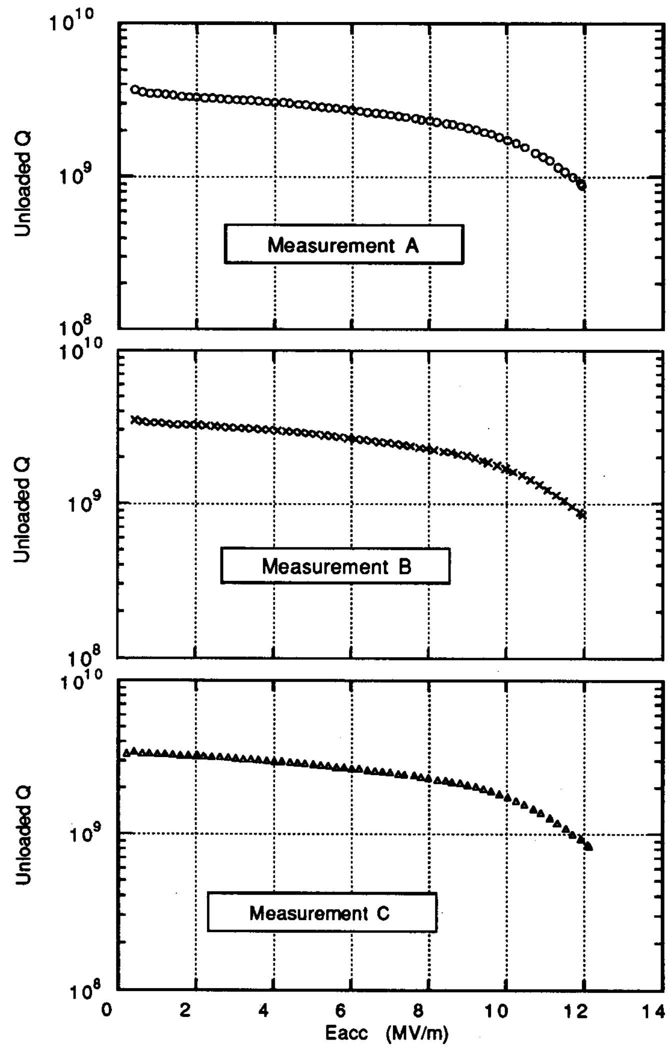

Fig. 2 Q_0 vs Eacc at Each Thermal Cycle

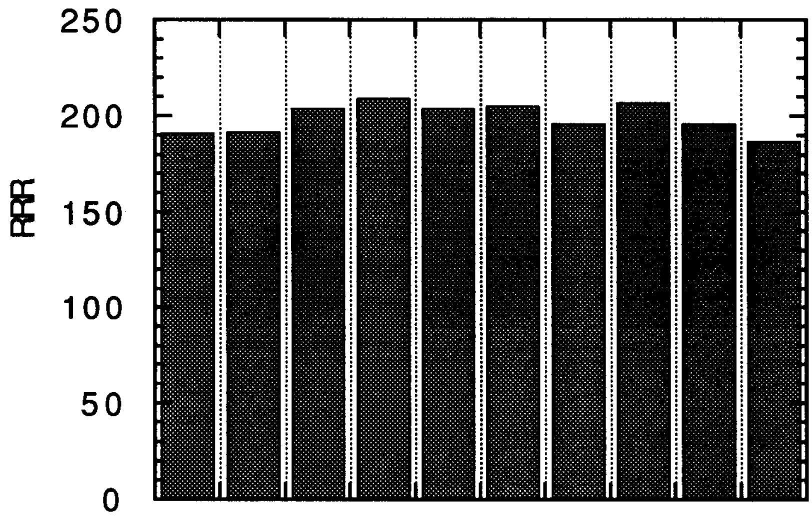

Fig. 3 RRR Distribution of Niobium Sheets for MR-18a Cavity

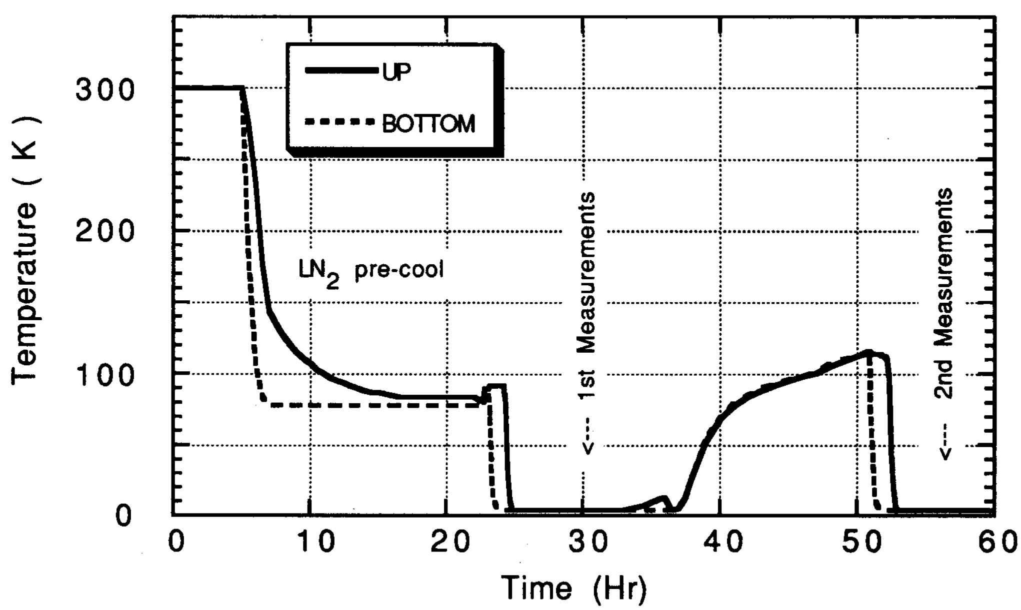

Fig. 4 Thermal Cycle for a TRISTAN 5-cell Cavity (MR-18a)

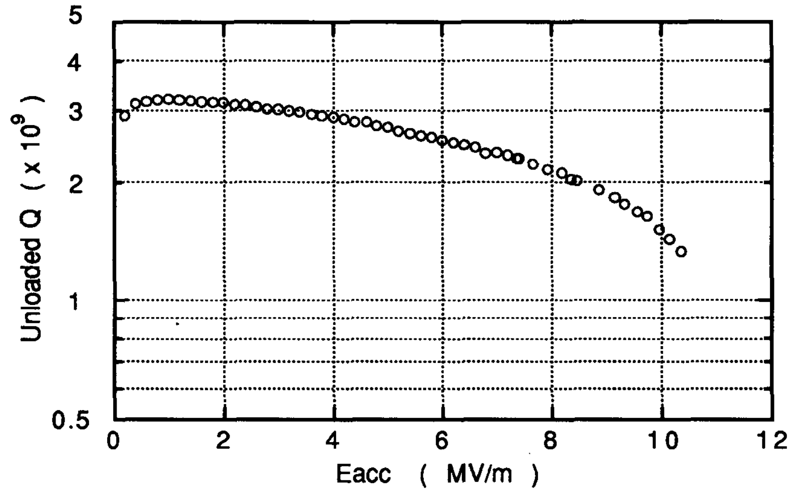

Fig. 5(a) Q_0 vs Eacc of MR-18a (1st Measurement)

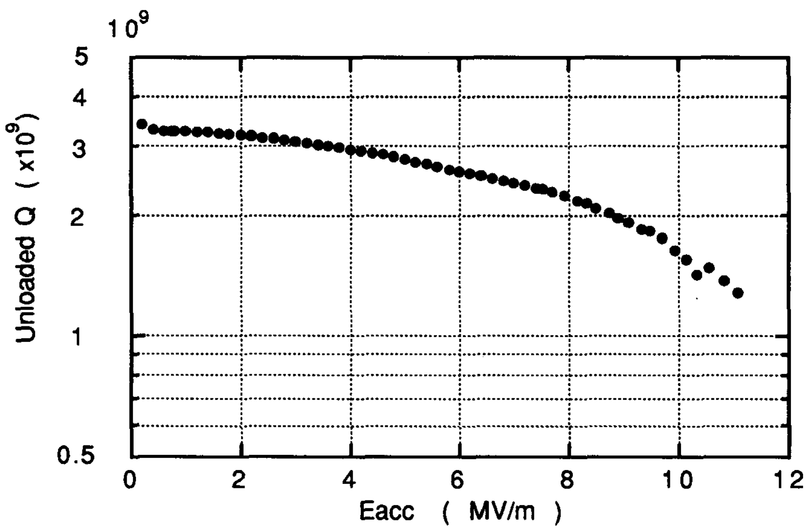

Fig. 5(b) Q_0 vs Eacc of MR-18a (2nd Measurement)