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RF PROPERTY OF THE TRISTAN SUPERCONDUCTING CAVITIES

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Abstract Upgrading of TRISTAN energy by superconducting cavities is under way. Sixteen 5-cell cavities have been installed and operated since November of 1988. Installation of other sixteen cavities has been almost finished, then the energy of TRISTAN will be raised to $\gtrsim$ 32 GeV in the next operation. In this paper, RF property of cavities and other RF components, long term performances and some operating experiences are reported.

INTRODUCTION

The R/D on the superconducting cavities for TRISTAN started in 1979, and the first beam test of a 3-cell cavity was performed in 1984. After the second beam test of a prototype 5-cell cavity in 1986, the energy upgrading program with 32 cavities started in 1987[1,2]. The last beam test with two 5-cell cavities in 1987 ~ 1988 gave us confidence for the operation in TRISTAN. In this beam test, the superconducting RF system stored the single bunch beam of 69 mA, accelerated 25 mA with a field gradient (Eacc) of 5.7 MV/m and transfered the RF power of 86 KW to the beam.

MEASURING PROCEDURE AND RESULTS

A pair of cavities which have been confirmed to have better performances than design values in a vertical cryostat (vert. test)[3], are assembled in a horizontal cryostat with couplers, beam pipes, gate valves and frequency tuners. During the assembly, cavities are leaked twice with filtered N_2 gas. Input couplers and gate valves are mounted in a laboratory atmosphere with portable clean huts, but the other works are done in a clean room of class 100. In all works, N_2 gas is overflowed.

Before the assembly, a pair of input couplers are rinsed with acetone and ultra pure water in a ultrasonic bath, baked at 125°C for more than two days and tested up to 200 KW. 4 couplers among 46 couplers have been leaked by arcing in this test, but after adopting arc detectors, 22 couplers have been safely tested. HOM couplers are machined to tune the fundamental filter frequency and then chemically polished[4].

After the final leak test, the assembled cavities are measured (Table I) and high power tested at 4.4°K in a laboratory test stand. For the latter 16 cavities, input couplers have been tested up to 60 ~ 75 KW in total reflection condition at the room temperature.

TABLE I RF property of 32 superconducting cavities

Load free frequency	508.28 ~ 508.50	MHz
Frequency change / length change ($\Delta f/\Delta l$)	72 ~ 85	KHz/mm
Spring constant	92 ~ 146	kg/mm
Δf/He pressure change at load free	~ – 40	KHz/kg/cm^2
at 500 kg loaded	~ – 22	KHz/kg/cm^2
Stroke of piezo-electric fine tuners	5.1 ~ 7.1	KHz/1600 V
Step response of frequency tuning loop	20	msec
External Q of pick up probes	1.3 ~ 5.7	x 10^{11}
External Q of HOM couplers for the accelerating mode	> 2.6	x 10^{10}
Longitudinal impedance of TM_{011} family	$\lesssim$ 2	MΩ
Transverse impedance of TE_{111} and TM_{110} families	$\lesssim$ 50	MΩ/m
RF coupling between paired cavities	~ 0.1	% (field)
Mechanical coupling between paired cavities	7 ~ 10	% (frequency)

A high power test is done separately. In the Eacc of 0.15 ~ 1 MV/m, two side multipactings (MP) at capacitive gaps of HOM couplers are observed with vacuum pressure rise, change of output power from HOM couplers and heat pulses of carbon thermometers on HOM couplers. This MP is processed within half an hour. Another MP around the input coupler port is sometimes observed in higher Eacc ($\gtrsim$ 4 MV/m), with heat pulses and electrons picked up by biased field monitor probes below the input couplers. In this case, however, no change of vacuum pressure is observed because vacuum gauges are set on warm beam pipes far from the input couplers. It takes 2 ~ 5 hours to reach Eacc, max.

Usually cavities have not been sufficiently aged due to limited time and LHe, and sometimes we have stoped aging because of higher input power. Therefore it is not possible to discuss a correlation between Eacc,max of vertical and horizontal tests. But generally there are degradation of Eacc,max (Fig. 1).

Q_0 values have been measured by LHe consumption. Though this method gives large errors of ~ ± 20 % and the difference of ~ 10 % due to the temperature difference between the vertical (4.2°K) and the horizontal (4.4°K) test must be considered, there is also the degradation but no correlation. The degradation is definite in the electron field emission. Generally it starts at lower field and has larger ß value.

TABLE II High field performance of 32 cavities

Cavity No.		Q_L (x10^6)	Q_0 (x10^9) at Eacc (MV/m)		Eacc, max	Ie(nA) at Eacc	beta
			Hor. Test	MR, 19 July	Hor. Test	MR, 29 July	
D10-	A1	1.10	1.6 at 6.6	2.2 at 5.5	6.8	2.3 at 7.0	520
	A2	1.10	2.1--6.5	2.2--6.0	7.2	7.2--7.0	500
	A3	1.15	2.6--5.1	1.3--5.0	6.6	8.9--5.8	660
	A4	1.25	1.9--6.3	1.9--6.0	7.3	10.0--7.0	560
D10-	B1	0.80	1.7--6.9	0.6--4.0	7.1	42.0--4.3	800
	B2	1.05	1.6--6.1	1.1--4.5	7.1	30.0--5.2	570
	B3	1.30	2.8--6.8	2.2--6.0	7.8	1.1--6.9	520
	B4	1.25	2.4--7.0	2.5--6.0	8.0	1.5--8.0	–
D11-	A1	0.96	2.3--6.9	2.2--6.0	7.6	0--7.5	–
	A2	0.75	1.5--4.2	1.5--5.0	4.7	2.0--5.8	720
	A3	1.05	2.4--5.4	2.1--5.0	5.6	0.2--5.5	580
	A4	1.05	1.4--5.9	2.1--6.0	6.1	5.0--7.5	430
D11-	B1	1.20	2.1--8.0	2.2--6.0	9.4	3.2--8.0	480
	B2	0.95	1.9--5.5	1.4--5.5	6.6	4.9--5.6	580
	B3"	0.74	1.9--6.0	1.3--6.0	6.9	5.0--6.5	570
	B4"	0.71	2.0--6.0	1.5--6.0	6.9	0.7--6.8	380
			Hor. Test	Vert. Test	Hor. Test	Hor. Test	
D10-	C1	0.84	2.1 at 7.0	2.3 at 7.0	8.2	9.0 at 8.0	500
	C2	0.84	1.5--7.0	2.1--7.0	7.7	7.8--7.6	540
	C3	0.86	2.5--6.0	2.4--6.0	8.1	1.8--7.6	–
	C4	0.78	1.6--6.0	2.6--6.0	7.4	170.0--7.0	1000
D10-	D1'	0.82	1.5--6.0	2.7--6.0	6.7	4.4--6.6	560
	D2'	0.88	2.0--5.0	----------	>5.5	16.0--5.2	860
	D3	0.80	2.5--6.0	2.4--6.0	7.4	0.4--7.3	420
	D4	0.87	1.6--6.0	2.5--6.0	7.2	48.0--7.0	940
D11-	C1	0.94	2.1--6.0	2.7--6.0	7.1	0.1--6.9	–
	C2	1.04	1.5--5.0	2.7--5.0	5.8	2.8--5.5	570
	C3	0.90	1.2--2.5	2.6--6.0	3.2	3.2--3.0	1100
	C4	0.85	2.0--6.0	2.6--6.0	7.0	0--7.0	–
D11-	D1	0.72	2.3--6.0	2.7--6.0	7.0	2.1--6.5	520
	D2	0.89	2.2--6.0	2.7--6.0	6.8	0.1--6.5	–
	D3	0.78	2.6--6.0	2.7--6.0	6.7	0.5--6.5	–
	D4	0.83	2.4--4.5	2.7--5.0	6.2	0--5.7	–

From these high field performances (Table II), it is clear that the degradation is a accidental phenomenon mainly due to dust contamination and more careful assembly can push up Eacc,max in the horizontal test.

LONG TERM PERFORMANCE OF 16 CAVITIES

Up to now, cavities have been cooled down 3 times in the tunnel. Accumulated time amounts to ~ 5000 h at 4.4°K and ~ 3100 h with beam (Fig. 2 (d)). In the meantime, the ceramic windows of cavity 11B3' and 10B1 have been leaked. Though the leaks have not caused boiling of LHe, 11B3' and B4' have been contaminated, and then replaced by B3" and B4" in April. For the cavity 10B1, we have replaced the input coupler and continued operation. This cavity has not been degraded, though has been degraded before then.

The residual gas pressure is $\lesssim 5 \times 10^{-10}$ Torr without beam and $0.5 \sim 2 \times 10^{-9}$ Torr with beam. A 5-cell cavity has a volume of 250 l and a surface area of 3.5 m^2.

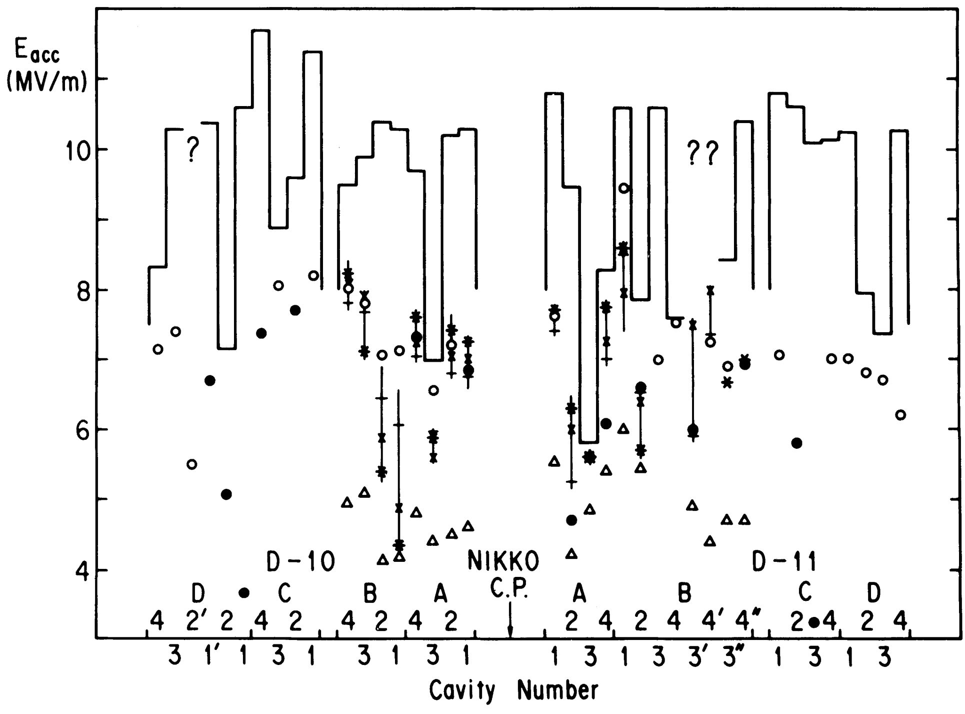

FIGURE 1 Field gradient reached at various stages. —: vert. test, ?: no vert. test, O: hor. test, expected to go higher, ●: hor. test, kept almost constant in successive BD of more than 5 times, +, x, *: MR on 8 Nov., 6 Jan. and 29 July, error bar (|) shows the range of other measurements, △ : max. operating gradient.

Assuming that gas components which are perfectly adsorbed to the cavity surface have a partial pressure of 2×10^{-10} Torr, and that monolayer molecular density is $8 \times 10^{14}/cm^2$, the amount of adsorbed gas becomes 9 layers after 100 days.

The radiation measured at the beam pipes is usually less than 1 KR/h at the operating Eacc, but near the cavities which show heavy field emission it exceeds 5 KR/h. The radiation from the beam also has been measured at the same place. Generally it is less than 1 KR/10 mA·h, but at some places it amounts to 10 KR/10 mA·h, though a radiation mask having an aperture of 8 cm is set at the bending magnet side of each cryostat.

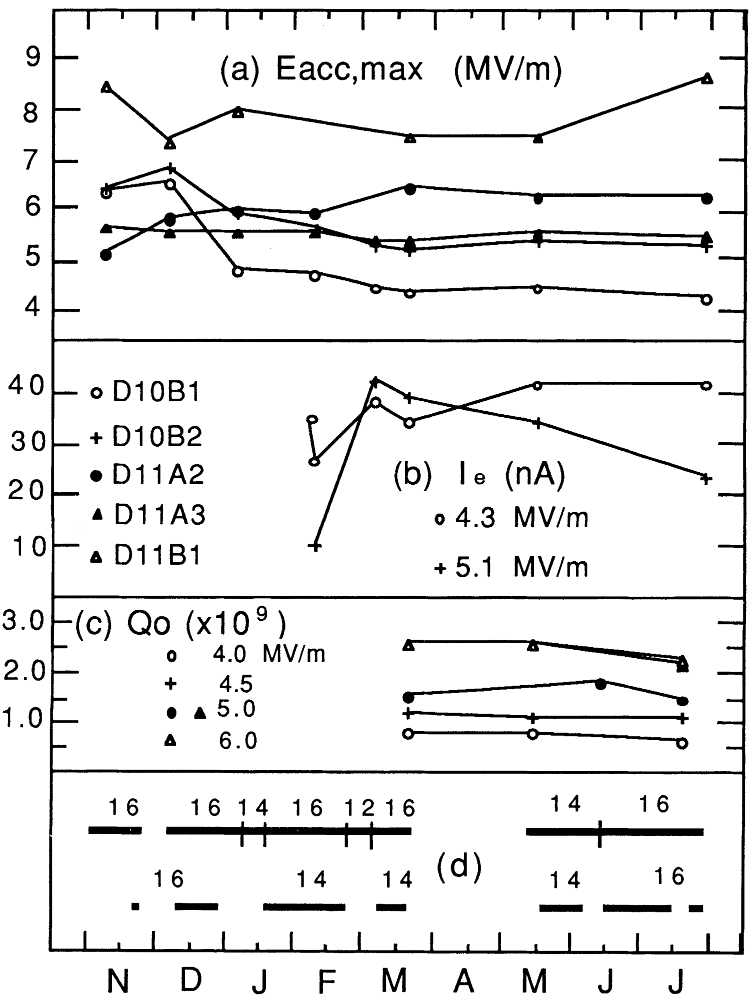

FIGURE 2 Examples for variation of Eacc,max (a), field emission current (b) and Q_0 (c). (d) shows numbers of cavities at 4.4°K (upper) and operated cavities (lower).

Eacc,max have been measured frequently (Fig. 1). They seem to be not degraded except those of cavities D10B1 and B2, which are in the same cryostat and have shown degradation at the same time in the early stage of operation (Fig. 2 (a)) probably by dust from somewhere. These cavities have heavy electron loading at rather lower Eacc (Fig. 2 (b)). Improvement of the cavity D11A2 has been obtained by replacing the input coupler after horizontal test. The temperature rize of cooling water for ceramic windows is not changed until now.

OPERATION[5]

16 cavities are now operated with an average Eacc of 4.4 MV/m and a beam current of 10 mA. The beam current is limited to 11 mA by a trouble of two N type connectors of HOM couplers and not by any beam instability. This trouble has been caused by excessive fundamental power (~ 1 KW) due to break down (BD) of HOM couplers which changes the filter frequency. HOM power extracted is 30 ~ 50 W/coupler at 10 mA and RF power transfered to the beam is 40 ~ 70 KW/cavity.

Because 4 cavities are drove by one klystron, an average Eacc is restricted by the cavity having the lowest Eacc,max. For the sake of stable operation, operating Eacc are set to be lower than 85 % of Eacc,max for any cavities (Fig. 1).

The number of RF switch off times by an interlocking system is 0.5/16 cavities in one physics run (100 min.). About 80 % of them are caused by the radiation from the beam and concentrated on two adjacent cavities (D10A4, B1), where the radiation level from the beam is high. They moves one to another by changing COD of the beam, so more elaborate tuning is expected for stable operation.

A quench detector, detuning offset scheme for phase stability and RF recovery procedure under the beam circulation work well[6].

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