SUPERCONDUCTING CAVITY BEAM TEST IN THE TRISTAN ACCUMULATION RING

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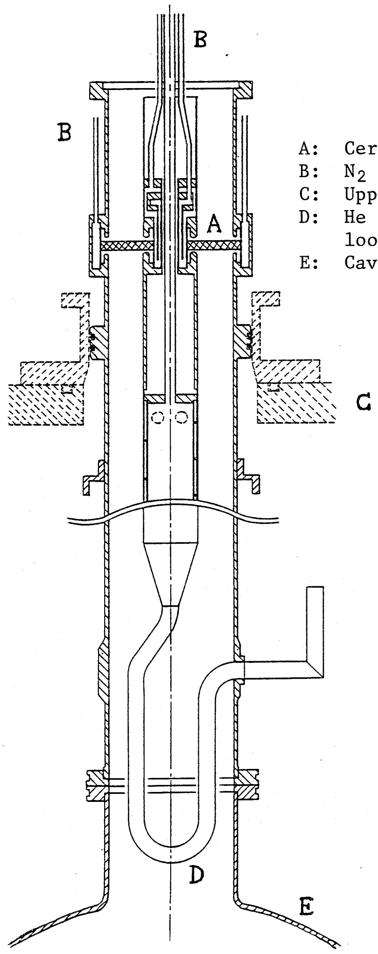
INTRODUCTION

A three-cell 508 MHz superconducting niobium accelerating structure has been tested in the TRISTAN Accumulation Ring$^{1)}$. The objective of this beam test was to demonstrate the feasibility of using superconducting cavities in the TRISTAN Main Ring. One of the most difficult problems associated with the use of superconducting cavities is to dump beam induced higher order modes (HOM's) sufficiently so that these HOM's do not cause instability and additonal He loss due to multi-turn effect. Although the number of the cavity installed in the TRISTAN Main Ring will be several tens, the difference in the machine parameter and operating condition is such that this test places more than 10 times severe constaints on the HOM damping comparing with the operation in the Main Ring. Two other important components in practical use, a tuner and an input coupler, were not designed satisfactorily but tentative ones were used.

Although some technical diffeculties were encountered, the feasibility of using the superconducting cavities in the Main Ring has been demonstrated by this beam test.



A: Ceramic window
B: N_2 gas cooling pipe
C: Upper plate of cryostant
D: He gas cooled coupling loop
E: Cavity

Fig. 1 77 D input coupler.

EXPERIMENTAL SETUP

Cavity

The fabrication and the performance of the cavity is reported by Furuya in this proceedings. The cavity was fully equipped with an input coupler, three HOM couplers and a monitor coupler for each cell. The cavity Q value was measured in the beam line at several field gradient (Eacc) by measuring the He consumption. For example Q_0 of 7.9 × 10^8 at Eacc of 3.7 MV/m was observed. The maximum Eacc was 4.3 MV/m and was limited by heating around the input coupler port.

Input coupler

The input coupler (Fig. 1) is set on the equator of the center cell. The input power is supplied through a waveguide and a coaxial T-stub. Inner and outer conductor are mostly made of copper plated stainless steel to reduce heat flow from the outside of the cryostat, and cooled by He gas flow. Unfortunately the crack was formed at the head of the coupling loop during the first beam test,then it was changed to a copper pipe. As a result Q value of the input coupler became 1.3 × 10^7 from the former optimum value of 2.2 × 10^6.

HOM coupler

Two types of couplers made of niobium were used. A loop type coupler (Fig. 2) with a filter for the accelerating mode was set on the equator of one end cell and two antenna type coupler (Fig. 3) were on the other end cell. They are oriented to ± 45° from the vertical direction. The polarization of dipole modes are determined by the input coupler port or by the antenna couplers. Q values of the input and HOM couplers were measured for longitudinal modes of frequency up to 1.5 GHz and 1.3 GHz for the other modes. The measured frequency and the loaded Q are listed in Table I and II, where two modes of low coupling impedance, TE_{121} and TM_{112}, are neglected. Q value of the loop HOM coupler for the accelerating mode was 1.5 × 10^9.

Tuner

A mechanical and two piezo electric tuners were prepared. Both are such types as change the total

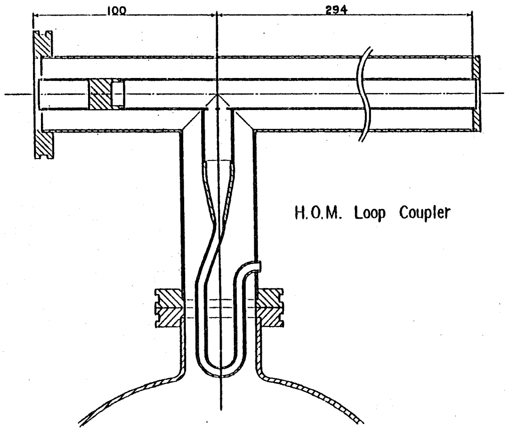


Fig. 2 39 D loop coupler.

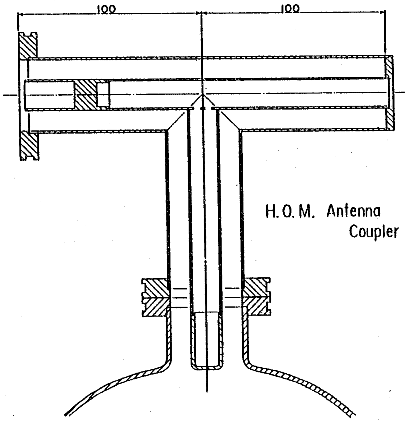


Fig. 3 39 D antenna coupler.

length of the cavity. The mechanical tuner can change the total length by ± 1.7 mm corresponding to the frequency change of ± 250 KHz with smallest step of 7 Hz. But the system has backlash of 0.5 to 2 KHz depending on the tuner position, so it was used only for pretuning. The piezo tuner is made by stacking 100 disks of piezo electric ceramics and is 72 mm in length and 16 mm in diameter. The maximum displacement is 37 μm with rated voltage of 400 V corresponding to the frequency change of 3 KHz.

Cryogenics

Figure 4 shows the horizontal cryostat for the three cell cavity. The design was especially restricted by the limited height of the ceiling of the tunnel. Static loss of the cryostat is 12 W and the loss of the cavity is for example 40 W at Eacc = 4 MV/m, so the total refrigeration power of about 65 W is needed, including the heat loss of the He transfer system. Cool down from the room temperature to the He temperature is done by the refrigeration mode in which the refrigerator is directly connected to the cryostat, it takes ∿ 36 hours. During the beam test, liquid He is transfered from a 1000 liter reservoir. The pressure fluctuation in the He vessel was about 1 mb. A detailed description of the cryogenic system will be reported elsewhere.

BEAM TEST

General

At the end of May 1984, an electron bunch of 4.2 mA was captured and stored at 2.5 GeV using superconducting cavity alone. Then the beam was acceelrated to 5 GeV with the field gradient of 3.5 MV/m. The field gradient was increased up to 4.1 MV/m. But in waiting the beam, a vacuum leak developed at the input coupler. The He gas flow to cool the inner conductor was insufficient and the coupling loop was heated up and got a crack. While the input coupler was being repaired, the cavity was rinsed by HF, pure water and methanol. The second beam test was done at the beginning of July 1984. First of all, the field gradient was calibrated at 5 field gradient by measuring the synchrotron frequency. The calibrated field gradient was 3 ± 1 % higher than that evaluated using the transmitted power of monitor couplers and their external Q value from low power measurements. Normally the tuning was not done by the tuner but the master oscillator followed the resonance freqeuncy.

The results obtained during the beam test are summarized as follows.

a) The maximum field gradient was 4.3 MV/m and the beam was accelerated to 5.2 GeV by the superconducting cavity alone. The field was limited not by the cavity itself but by slow heating at somewhere around the input coupler port. No processing was needed to get this maximum field. This field gradient is highest in those of the superconducting cavities tested in the storage rings[2,3,4].

b) The maximum single bunch current stored at 2.5 GeV was 10mA, which was limited by heating of the rubber gaskets of the gate values at both ends of the cryostat.

c) The maximum power transferred to the beam was measured by accelerating the beam to 4 GeV. The maximum current held was 4 mA corresponding to the power of 4 KW. This was also limited by the heating around the input coupler port.

d) HOM coupler worked well but the development of the input coupler is needed.

e) The piezo tuner worked well. In spite of high loaded Q value, a single bunch of 8.7 mA was stored using the piezo tuner and the fixed driving frequency.

f) Additional He loss by the beam was measured with the beam of 10 mA held at 4 GeV by normal cavities. It was not detected.

HOM study

HOM modes were studied with a single bunch beam stored by normal cavities at 2.5 GeV. Many modes were scanned by the mechanical tuner according to the diagram shown in Fig. 5 and 6. To confirm the resonance condition, the spectrum of the HOM coupler output was monitored. The beam instability was monitored by the TV image of the synchrotron radiation light. Attenuation of cables and other RF components was calibrated as a function of freqeuncy.

Longitudinal modes

Six longitudinal modes were brought to revolution harmonics. The measured HOM losses normalized to 10 mA are listed in Table I. The calculation of HOM losses are done with R/Q given by SUPERFISH, the measured Q_L and assuming a bunch length of 1.2 cm. They agree within factor 2. The current dependence of HOM loss was measured with TM_{020}-π/2 mode and showed good I^2 dependence.

Robinson instability was also examined at the upper fs sidebands of the revolution harmonics. The instability was not observed except for the accelerating mode. The bunch lengthening was not measured.

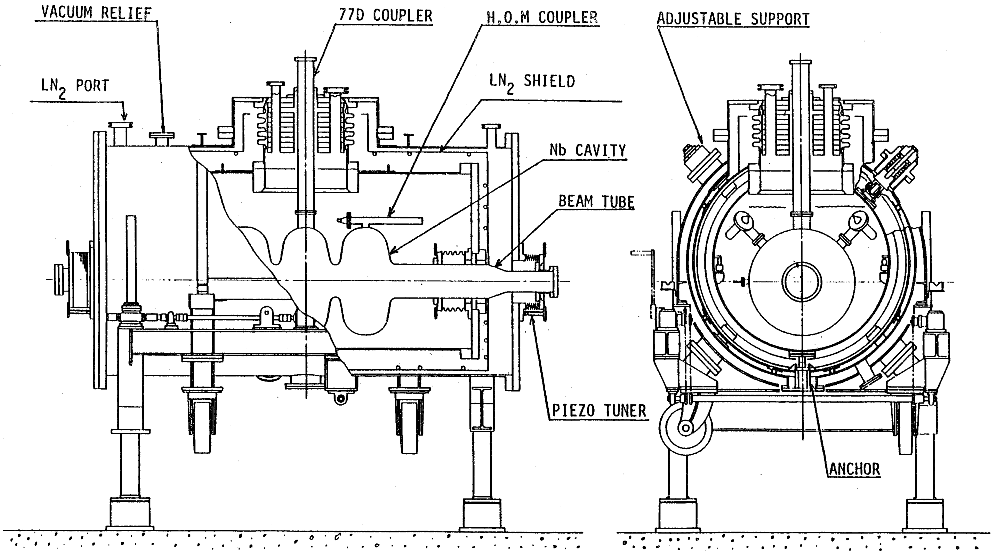


Fig. 4 Horizontal cryostat.

Table 1 Longitudinal modes and HOM loss

MODE		Freq. (MHz)	R/Q (Ω)	Q_L meas.	Ploss meas. (w)	Pcalc. (w)
TM_{010}	0	504.82	< 1.3	5.6×10^6		
	π/2	507.34	< 0.006	$\sim 1 \times 10^8$		
	π	508.58	395	1.3×10^6		
TM_{011}	0	953.06	109	3.3×10^4	0.68	off reson.
	π/2	946.99	13.4	3.2×10^4	0.17	off reson.
	π	941.60	2.6	7.0×10^4	31.7	18.3
TM_{020}	0	1079.90	0.13	1.8×10^6	45.8	24.4
	π/2	1088.57	0.13	1.4×10^6	17.5	17.9
	π	1096.24	0.05	7.4×10^5	0.001	off reson.
TM_{021}	0	1421.83	0.01	1.3×10^5	1.0	0.11
	π/2	1384.65	1.50	4.2×10^4	4.3	5.57
	π	1369.84	2.94	9.9×10^4	17.9	26.0

Table II Transverse higher order modes

Mode		Polari.	Freq. (MHz)	R /Q (Ω/m)	Q_L	Threshold current (mA)
TE_{111}	0	+ 45°	689.74	40	6.6×10^5	4.1 *
		- 45°	689.78		6.8×10^5	4.0 *
	π/2	- 45°	702.09	290	2.1×10^5	1.8 *
		+ 45°	702.43		2.4×10^5	1.6 *
	π	- 45°	721.40	212	2.8×10^5	1.8 **
		+ 45°	721.68		8.2×10^4	6.2 *
TM_{110}	0	Ver.	749.67	73	4.3×10^5	2.5
		Hor.	750.66		3.2×10^5	3.3
	π/2	Ver.	746.01	274	9.3×10^4	3.0 *
		Hor.	746.25		2.3×10^5	1.2
	π	Ver.	733.70	99	1.8×10^5	4.3
		Hor.	734.43		1.1×10^5	7.2
TM_{111}	0	+ 45°	1034.26	511	4.4×10^5	0.5
		- 45°	1034.56		2.1×10^5	1.1 *
	π/2	Ver.	1039.94	8.7	6.8×10^4	136 *
		Hor.	1040.48		7.3×10^4	125
	π	- 45°	1057.36	39	1.1×10^5	26.6
		+ 45°	1058.05		1.2×10^5	23.8
TE_{112}	0	Hor.	1140.34	1.2	8.2×10^3	
		Ver.	1141.10		8.1×10^3	
	π/2	Ver.	1122.90	7.3	2.8×10^4	
		Hor.	1123.39		2.8×10^4	400 *
	π	Ver.	1161.90	58	1.1×10^5	13.3 *
		Hor.	1063.44		8.4×10^4	16.8 *

* Brought to betatron sidebands
** Vertical oscillation without beam loss

Transverse modes

The beam instability were examined with a single bunch of 6 mA and the accelerating field of 2 MV. As is shown in Fig. 6, many modes were brought to the lower betatron sidebands of revolution harmonics. The results are listed in Table II. The beam instability was observed only by TE_{111}-π mode (721.3 MHz) with vertical oscillation of the TV image without beam loss. This instability was also observed at a current of 3 mA but the dependence on beam current and accelerating field was not measured. The spectrum of the HOM coupler output is shown in Fig. 7, where the lower vertical betatron sideband is much enhanced. The threshold currents for the transverse coherent dipole mode were calculated using the formula given by Suzuki and Yokoya[5], wher the measured damping time of 15 msec[6] for betatron oscillation was used. The transverse coupling impedance was calculated by URMEL and was assumed to be reduced by factor cos45° for the modes polarized to the HOM coupolers. The disagreement is rather large (or small ?) and more systematic measurement is needed, for example, the measurement of the transverse impedance and damping effect due to other transvers modes.

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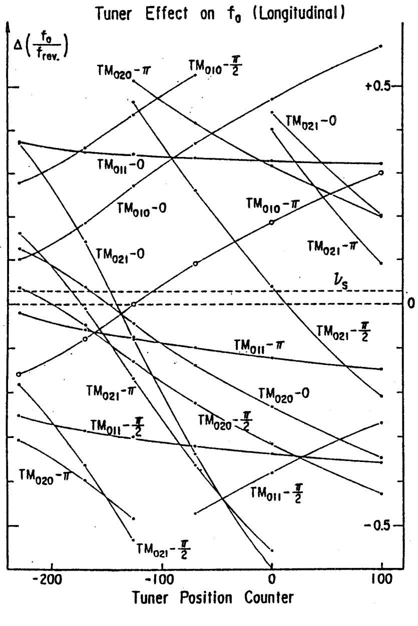

Fig. 5 Longitudinal modes.

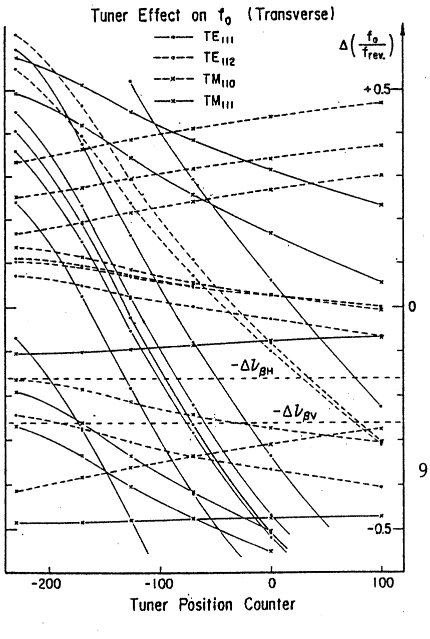

Fig. 6 Transverse modes.

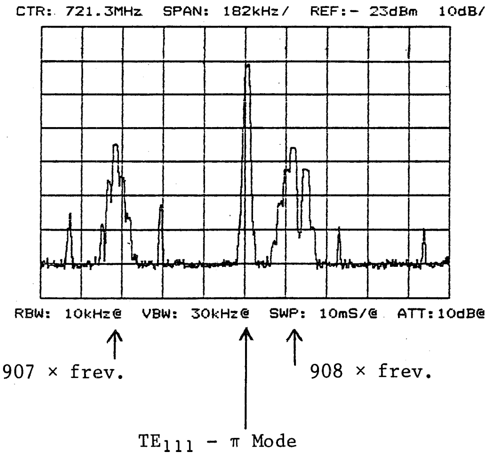

Fig. 7 Spectrum of a HOM coupler when vertical oscillation was observed.