HIGHER ORDER MODE COUPLER FOR TESLA

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1. ABSTRACT

Two types of HOM coupler for sc TESLA accelerating structure have been developed and partially tested. Both are, with some modification, based on existing designs. In this paper, results of rf measurement at room temperature and 2K are presented.

2. INTRODUCTION

Computation presented at LC92 [1] showed, that damping of **H**igher **O**rder **M**odes is of great importance for the operation and beam quality of the future superconducting linear collider TESLA. The high impedance of these modes yields to growth of the emmitance and increase of the energy spread. To provide Qext of HOMs below the **B**eam **B**lowup limit, each 1300 MHz accelerating structure, made up of 9 coupled cells, will be equipped with two HOM couplers placed outside the helium vessel on the beam tubes. In addition, the special end cell designs (asymmetric cavity) or the distance adjustment between neighboring structures (symmetric cavity) enhance the field of chosen dangerous HOMs at the couplers location and help to reach the required values of Qext. Both methods of the field enhancement were described in [2] and have since been verified with rf measurements on five copper models of the TESLA cavity. It is expected that 30 % of the beam induced HOM power, mainly deposited to modes under cutoff, can be extracted to the external loads by HOM couplers. The rest of the power should be absorbed by broadband beam tube absorbers, placed between two cryomodules.

3. HOM COUPLERS

Two types of HOM coupler have been proposed for the TESLA cavity. Fig.1 shows the layout of the demountable version of the coupler, based on the HOM coupler used for LEP superconducting 352 MHz sputtered cavities and scaled to the frequency 1300 MHz [3,4]. This version has been designed and tested at SACLAY. There is one main advantage of this coupler compare to the welded version which is shown in Fig.2 Easy mounting of such a coupler at the final assembling stage simplifies chemical cleaning and heat treatment of the cavity. The danger of this coupler is that the already clean cavity may collect dust particles during attachment of the couplers. Also some increase of the cavity cost by additional vacuum flanges and seals should be taken into account. The welded version, constructed and partially tested

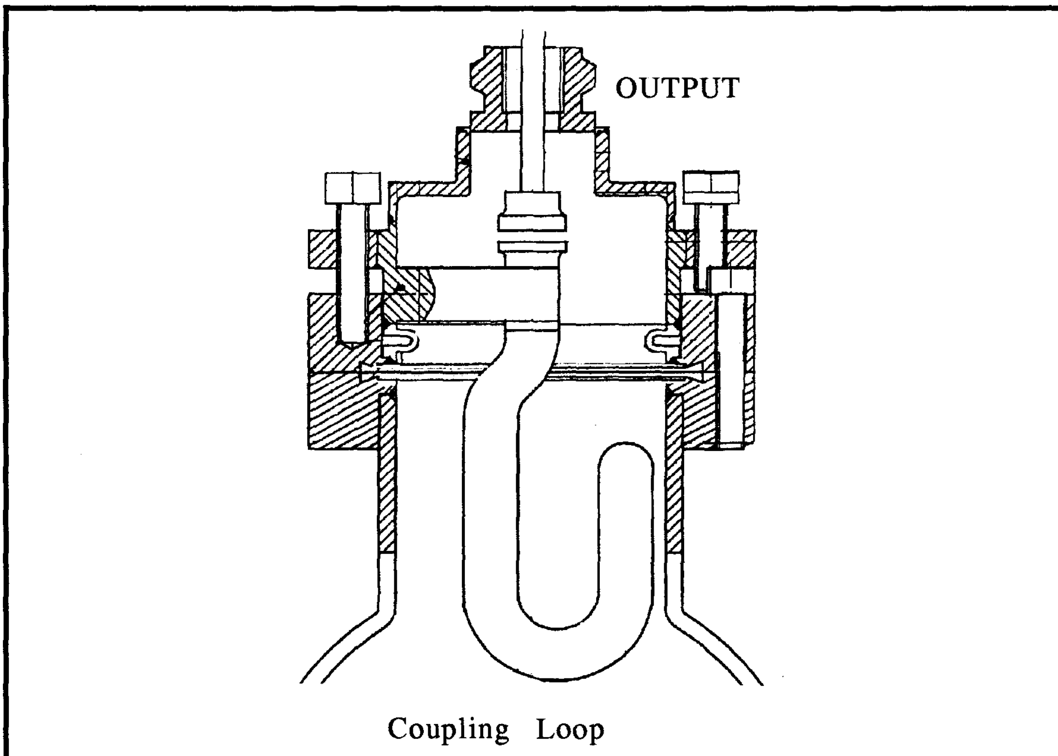

Fig.1 Demountable version of HOM coupler.

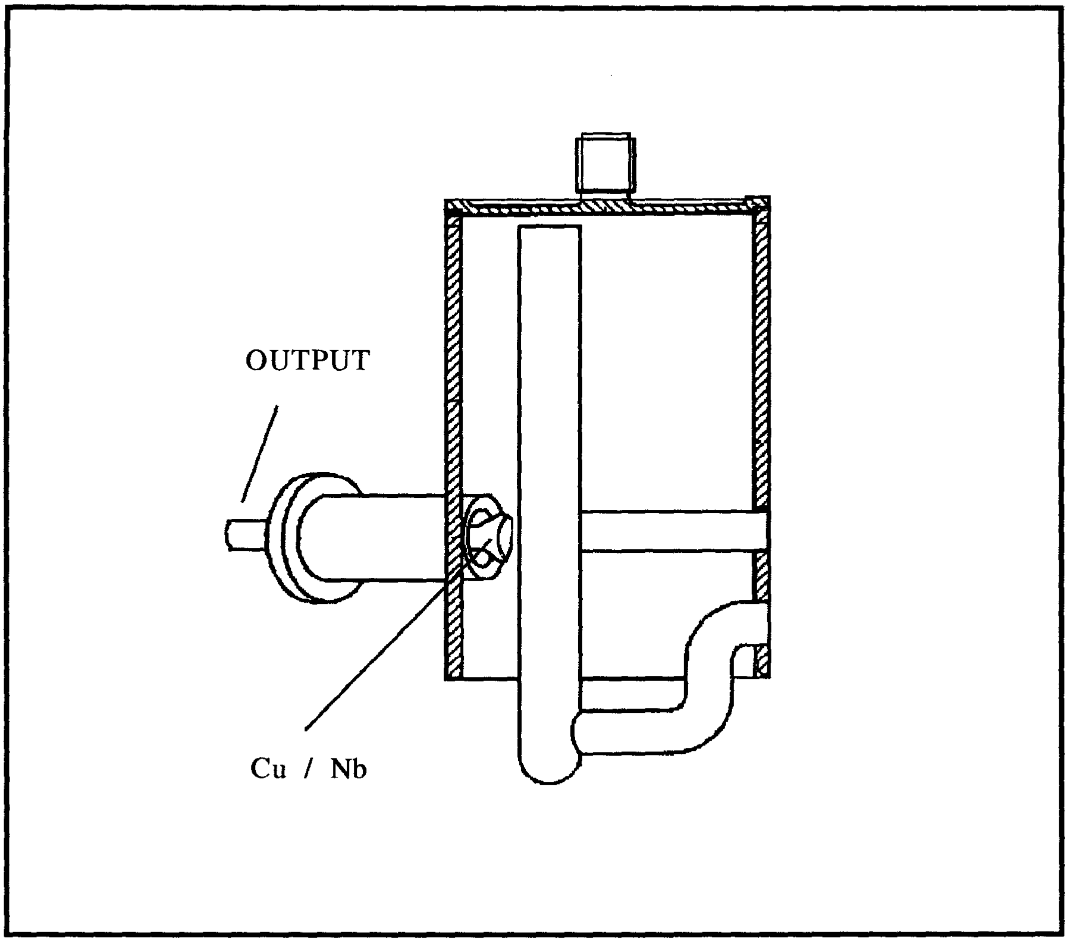

Fig.2 Welded version of HOM coupler.

at DESY, is based on the HOM couplers designed for the superconducting 500 MHz, 4-cell HERA cavities [5]. Three years of the experience with 48 couplers in the HERA electron ring showed that this type of coupler works stable without quenches in continuous wave operation mode at 4-5 MV/m and beam current up to 30 mA, even in presence of strong gamma radiation. The good cooling of the inner conductor by two stubs, makes the welded coupler less sensitive to the gamma and electron bombardment than the demountable HOM coupler. A disadvantage of this version is that the mechanically complicated inner part of the coupler requires more effort in the fabrication and makes more difficult the chemical cleaning and the heat treatment. On the other hand the probability of dust contamination is reduced since only small output flanges must be attached during the final assembling. It seems possible to simplify the fabrication of the inner part to lower cost of the coupler. The electron beam welded inner part, which consists of the inner conductor and two inductive stubs can be replaced by one part, fabricated as a whole, out of the 8 mm thick Nb material [6].

4. HOM DAMPING AND REJECTION FILTER CHARACTERISTIC

4.1 Measurements Setup

Many copper models of both versions have been built to optimize coupler dimensions, the position of the coupler ports and the orientation and penetration of the coupling elements. Figs.3 and 4 present arrangements for Qext measurements for modes under cutoff and above cutoff, respectively. Pairs of the welded couplers have been tested on the asymmetric cavity models. Pairs of the demountable couplers have been tested on both symmetric and asymmetric cavities.

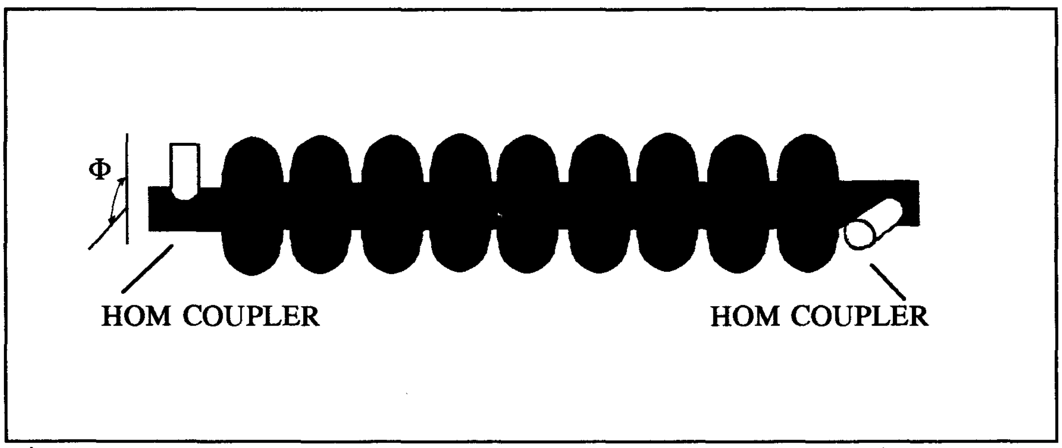

Fig.3 Layout of the measurement setup for modes below cutoff

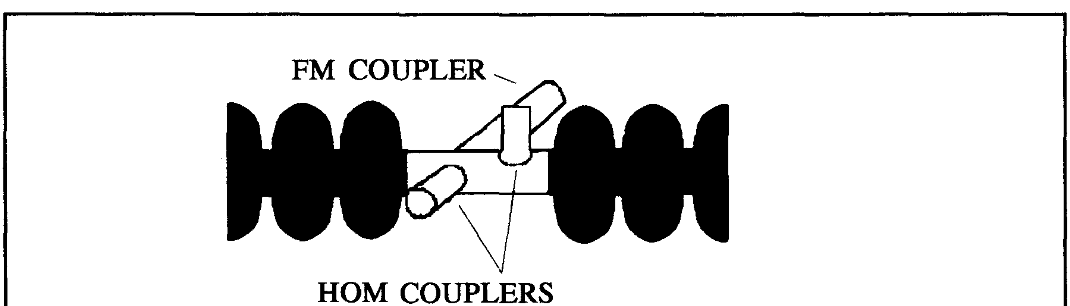

Fig.4 Layout of the measurement setup for modes above cutoff

4.2 Damping of HOMs

Tables 1 and 2 contain Qext values of dipole and monopole modes, measured for the most recent versions of both HOM couplers. The last column of Table 1 shows BBU limit (as it

Table 1 Values of Qext for the dipole modes

MODE		FREQ,	R/Q	2 welded couplers on asymmetric cavity	2 demount. couplers on asymmetric cavity	2 demount. couplers on symmetric cavity	BBU LIMIT
				Qext	Qext	Qext	Qext
		[MHz]	[Ω/cm²]	[1.0E+3]	[1.0E+3]	[1.0E+3]	[1.0E+3]
TE111	1	1622,2	0,01	193	290	210	
	2	1622,3		366	100	540	
	3	1629,8	0,14	48	40	60	
	4	1629,9		77	40	100	
	5	1642,2	0,03	25	16	19	
	6	1642,3		37	61	61	
	7	1659,1	0,75	42	12	7,6	
	8	1660,3		22	8,9	28	
	9	1681,2	0,04	11	9,1	5,6	
	10	1682,2		23	4	14	
	11	1706,7	10	4,8	2,2	2,3	8.1
	12	1707,8		5,5	4,5	7,4	8.1
	13	1734,0	15,4	3,4	3,6	1,1	7.5
	14	1734,3		4,5	1,6	3,2	7.5
	15	1762,1	2,23	2,7	4,1	2,2	7,4
	16	1762,2		3,2	1,8	3,2	7.4
	17	1786,5	1,4	2,1	4	2,8	
	18	1789,4		2,8	1,8	2,8	
TM110	1	1799,9	0,71	5,2	4,6	4	
	2	1800,9		4,2	2,1	13	
	3	1835,7	0,45	19,8	32	21	47
	4	1837,0		18,9	16	15	47
	5	1852,7	0,33	27,7	38	22	52
	6	1853,2		20,9	19	24	52
	7	1865,3	6,47	50,6	52	48	76
	8	1865,5		26,5	28	30	76
	9	1874,4	8,75	50,2	73	43	120
	10	1874,8		51,1	54	85	120
	11	1880,8	1,83	95,1	126	99	194
	12	1881,2		85,5	94	86	194
	13	1885,2	0,1	18,1	322	130	330
	14	1885,4		75,2	121	190	330
	15	1887,4	0,18	633	472	480	670
	16	1887,8		251	250	250	670
	17	1889,1	0,01	1800	3270	520	
	18	1889,4		1500	3270	1400	

Table 1 continuation

MODE		FREQ,	R/Q	2 welded couplers on asymmetric cavity Qext	2 demount. couplers on asymmetric cavity Qext	2 demount. couplers on symmetric cavity Qext	BBU LIMIT Qext
		[MHz]	[Ω/cm²]	[1.0E+3]	[1.0E+3]	[1.0E+3]	[1.0E+3]
TE121	1	3075,7	0,11	171	62	6900	1.0E6
	2	3076,0		229	1200	300	1.0E6
	3	3076,5	0,01	408	59	650	1.0E6
	4	3076,7		121	660	1600	1.0E6
	5	3077,5	0,02	569	140	520	800
	6	3077,6		79,5	210	2900	800
	7	3079,0	0,14	248	39	610	600
	8	3079,1		35	230	1400	600
	9	3081,9	0,92	94,3	27	11	800
	10	3082,1		44,5	41	17	800
	11	3087,4	1,27	43,7	10		600
	12	3087,7		75,9	52		600
	13	3097,0	0,16	33	27		
	14	3097,2		102	12		
	15	3113,3	0,02	16,8			
	16	3113,5		98,9			

Table 2 Values of Qext for the monopole modes

MODE		FREQ.	R/Q	2 welded couplers on asymmetric cavity Qext	2 demount. couplers on asymmetric cavity Qext	2 demount. couplers on symmetric cavity Qext	Qext Limit
		[MHz]	[Ω]	[1.0E+3]	[1.0E+3]	[1.0E+3]	[1.0E+3]
TM011	1	2379,6	0,00	350,0	1150	1600	
	2	2384,4	0,17	72,4	360	460	
	3	2392,3	0,65	49,5	140	220	
	4	2402,0	0,65	84,0	68	110	
	5	2414,4	2,05	32,0	70	97	
	6	2427,1	2,93	29,1	81	59	
	7	2438,7	6,93	20,4	66	49	1000
	8	2448,4	67,04	27,4	58	51	100
	9	2454,1	79,50	58,6	110	100	100
TM012	1	3720,0	1,26	3,0			
	2	3768,9	0,07	5,1			
	3	3792,2	0,75	5,2			
	4	3811,7	1,43	3,9			
	5	3817,5	0,18	15,2			
	6	3829,2	2,33	11,3			
	7	3839,8	0,77	40,0			
	8	3845,3	22,04	240,0			300
	9	3857,3	6,85	6,1			1000

was assumed for the calculation) of high (R/Q) dipole modes and of these modes which in the standard cavities, without the end cell modification or the distance adjustment, would be trapped (TE121 passband).

In the case of monopole modes, Qext values were chosen to keep peak power out of the coupler below the specification for the cables used in the TESLA cryomodules and to lower the heat losses due to their attenuation (~1 dB per cable, 16 HOM cables in each cryomodule).

The comparison of the measured Qext values with the BBU limit shows that both of the coupler types provide enough damping of those HOMs which have been taken into account in the emmitance growth calculation.

4.3 Broadband Characteristics

Preliminary computation and measurement confirm expectation that some of modes above cutoff of the beam tube can be trapped between two neighboring structures. Since the interconnection between two cavities is superconducting the only damping of these modes is possible by the HOM and FM couplers. To avoid build up of the parasitic fields one should use couplers with broadband characteristic. The transfer function of the welded coupler, measured up to 10 GHz (Fig.5), shows that in this frequency range this coupler can still provide HOM damping.

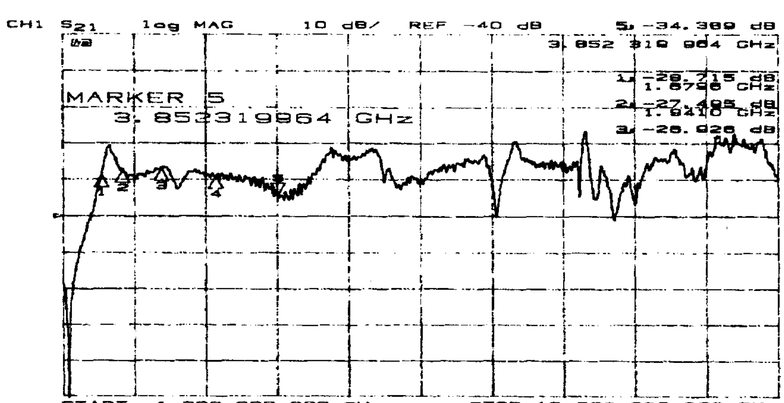

Fig.5 Transfer function of welded coupler. F=1.2+10 GHz

4.4 Angular Position

An angle of 150° between the two welded couplers belonging to one cavity has been chosen as an optimal position with respect to the eight highest (R/Q) dipole modes (quadrupole and sextupole modes have been assumed to be irrelevant for the emmitance growth). At the optimal angular position, the sum of impedances of eight dipole modes has the lowest value. The optimum is rather flat (Fig.6) and differs from the expected value of 90° since coupling mechanism for this coupler has both, electric and magnetic character. For the demountable couplers, an angle of 115° between two couplers has been found as the best angular position for this coupler type.

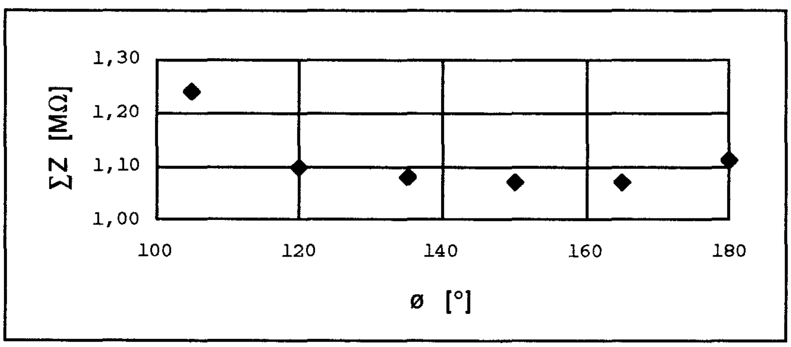

Fig.6 Change of ΣZ vs. angle between couplers.

4.5 Fundamental Mode Rejection Filter

The fundamental mode rejection filters of both couplers have been optimized for minimum rf power transferred from the cavity to an external load. The characteristic of the filter of the welded coupler, presented in Fig.7 (demountable coupler has similar filter behavior), shows that the filter detuning of ± 20 MHz causes reduction of the Qext to 5E9, which is still safe. For Q_{ext}=5E9 the mean value of the extracted power from the fundamental mode is only 1W at Eacc=25 MV/m (100 W peak). Both coupler versions give the technical possibility of final filter tuning after the coupler is already attached to the cavity. The adjustment makes the fundamental mode Q_{ext} higher then 1.E11, limiting the coupler power to less then 50 mW at 25 MV/m. During the TESLA operation rejection filters should stay very stable since the couplers are placed in the isolation vacuum, and no change of pressure difference between the isolation and the beam vacuum is expected. To lower cavity cost one may use the HOM coupler as the pickup probe. For this purpose Q_{ext} in the range from 1.E10 to 5.E10 should give enough signal to drive all electronic devices for phase and amplitude control.

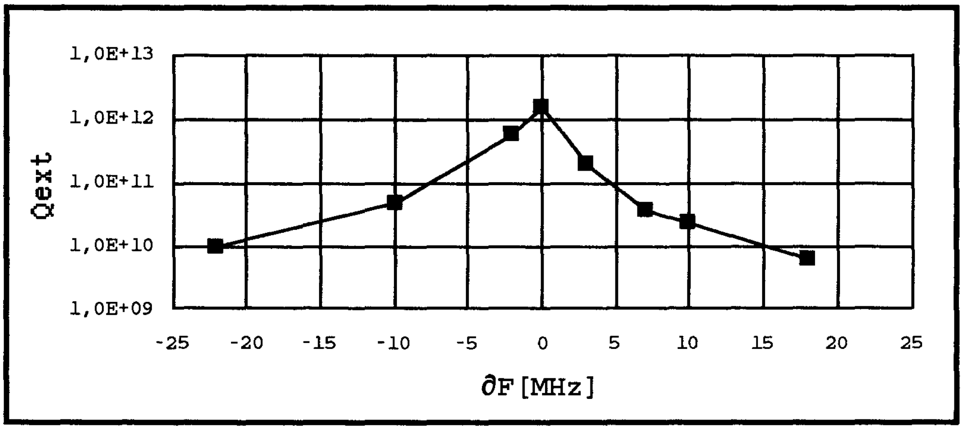

Fig.7 Change of Qext of welded HOM coupler measured on 9-cell cavity vs. filter detuning

5. COLD TEST OF HOM COUPLERS

5.1 CW Cold Test of 1.5 GHz Nb Models

The existing 1.5 GHz infrastructure at Saclay has been used for testing of HOM couplers at 4.2 and 2 K. Niobium models (RRR~300) of HOM couplers scaled from 1.3 GHz to 1.5 GHz had been prepared at Saclay [7] and tested on two 1.5 GHz single cell cavities. Fig.8 shows the setup used for the cold test. Couplers have been placed in vacuum as is foreseen later in the TESLA cryostat. Six temperature sensors were attached to the coupler and the beam tube for temperature mapping during the test. Fig.9 presents curves of Qo vs. Eacc, measured in cw operation. The welded coupler has been tested twice. For the first test (circles), the output antenna tip was made of low quality copper. The heat produced by the magnetic field at the output location (about 2 % of the field at the equator of the cavity) was high and the increase of the temperature was detected by all sensors placed near to the output flange. An additional heater mounted on the output flange has been used to estimate the total heat produced by the magnetic field. To get the same temperature maps as at 5 and 10 MV/m, the power of the heater was driven to 80 mW and 320 mW respectively. For the next experiment, the cavity was once more chemical cleaned (5μm) and the Cu part was replaced by the Nb part. The measurement of Qo vs. Eacc (triangles) has been continued until indication of the temperature increase of the output flange was detected. At this moment, the Qo drop from 1.8E10 to 6.5E9 has been measured. The test of two models of the demountable coupler showed, that in cw operation the coupling loop quenches at 12.7 MV/m. This part of the coupler is exposed to the magnetic field equal to 2.5 % of the field on equator, similar to

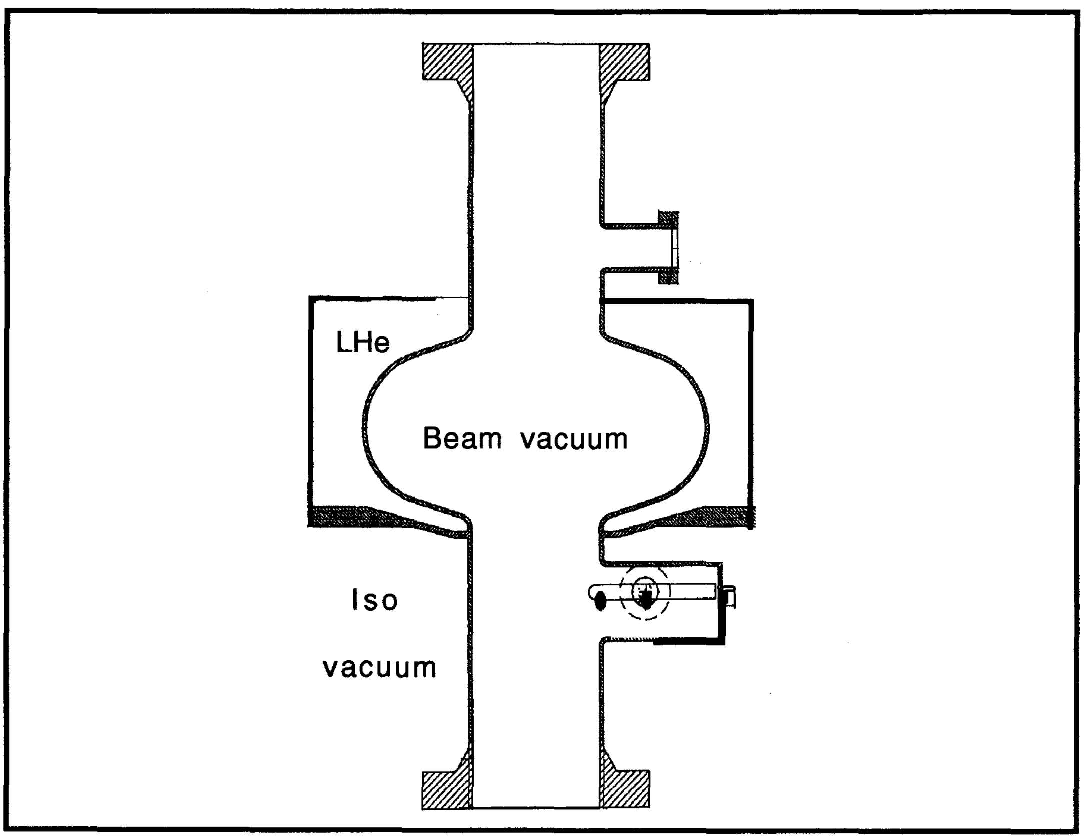

Fig.8 Cold test arrangement.

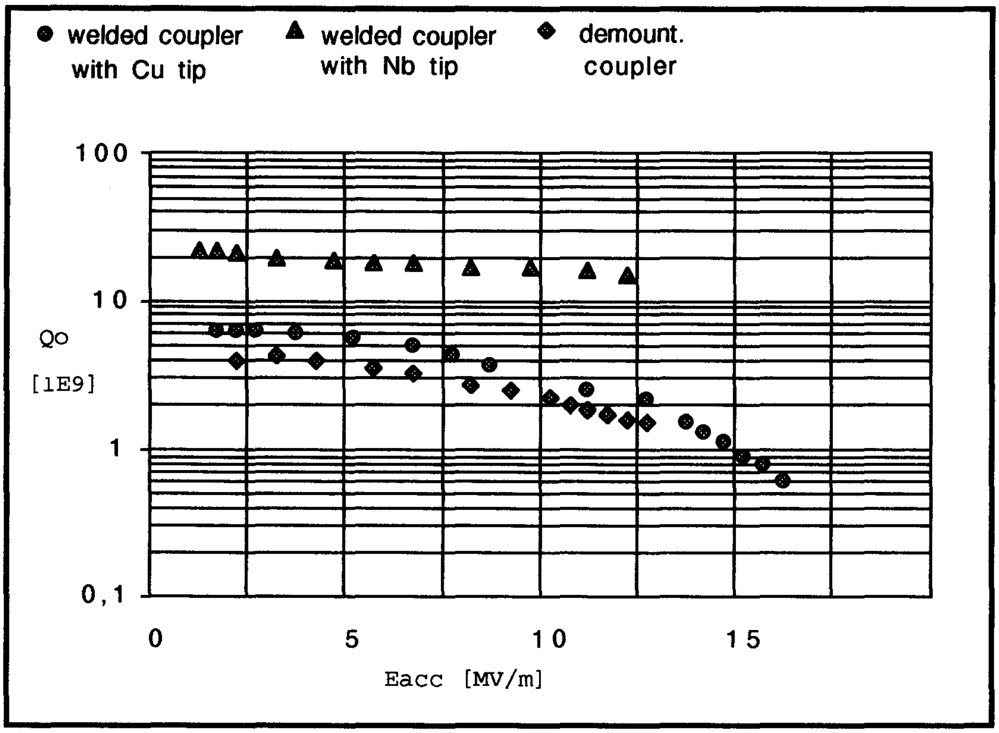

Fig.9 Qo vs. Eacc measured in cw operation mode.

the magnetic field surrounding the antenna tip in the welded coupler. Both parts are poorly cooled, so quenching at about the same field level seems to be reasonable. The curve showed in Fig.9 (diamonds) has been measured for the first Nb model of the demountable coupler. Here, the observed Qo drop at the quench point was from 1.2E9 to 5.0E8.

Fig,10 shows Qext of the fundamental mode, measured for the first model of the demountable coupler (diamonds) and the welded coupler with the Cu output tip (dots). One should note that, even in cw operation, both filters were very stable for the Eacc below 12.5 MV/m and kept Q_{ext} higher then 1E12.

5.2 Test of HOM Couplers in Pulse Operation Mode

The magnetic field heating of HOM couplers in the cw operation exceeds by far the heating expected for the TESLA operation in the pulse mode with duty factor of 1.4 %. Fig.11

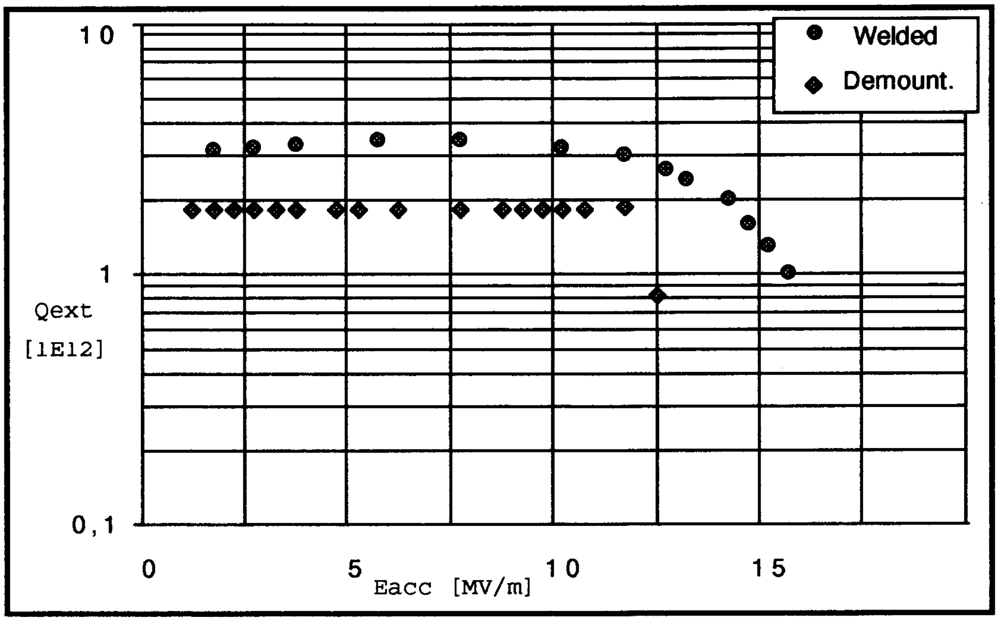

Fig.10 Fundamental mode Qext vs. Eacc

shows increase of the Eacc maximum vs. the duty cycle. The extrapolations of the both curves towards the shorter duty cycle cross the design value line Eacc=25 MV/m at duty cycle of 30÷35 %, which is still 20 times higer then duty cycle of

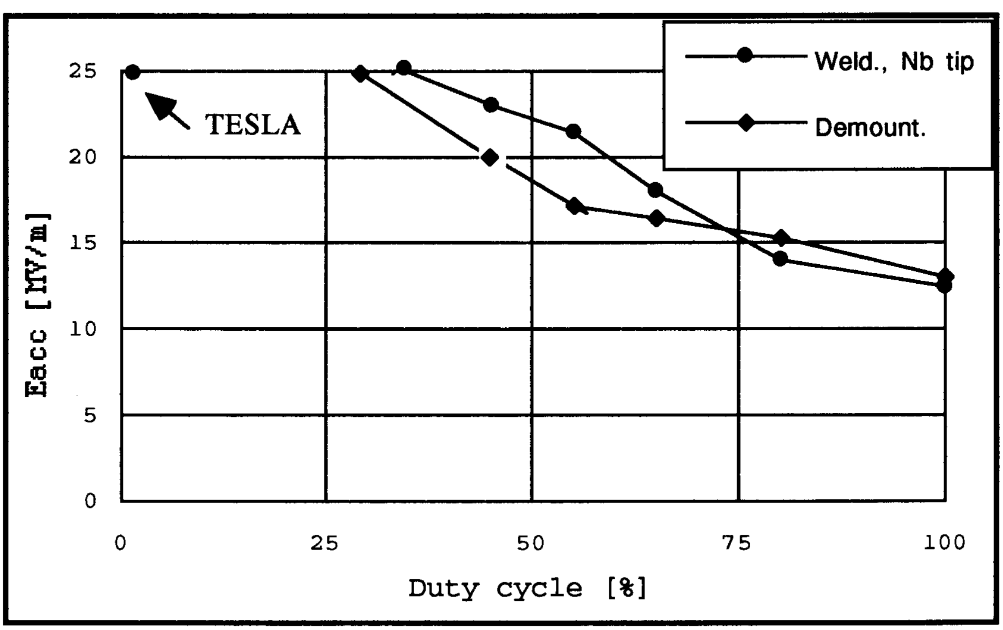

Fig.11 Maximum Eacc vs. duty factor

the TESLA collider. Unfortunately, measurements for this duty factor could not be made due to the quenching of both single cell cavities.

6.SUMMARY

The bench measurements and the cold tests of both versions of HOM coupler for the TESLA cavity showed that:

1. both couplers provide enough damping for all those modes which have been implemented in the emmitance growth calculation,
2. both couplers work properly up to 12.5 MV/m in **cw** mode and should work at 25 MV/m for TESLA duty cycle in the case of the normal electromagnetic heating,
3. both couplers show no multipactor,
4. both rejection filters work stably in the pulsed mode up to 20 MV/m.

The test on single cell cavity gives less possibility to observe the heating caused by the electron and the gamma bombardment. The coupling loop of the demountable coupler and electric antenna of the welded coupler penetrate 9 mm in the beam tube and are exposed to the dark current electrons and the gamma radiation. For the string of few multicell cavities (8 cavities are in one TESLA cryomodule) the energy deposited by the bombarding electrons or the gamma radiation may extend heating by the magnetic field of the fundamental mode and initialize quench of the coupler [8]. It seems unavoidable to test both coupler versions on at least 9-cell cavity to check if cooling of the couplers is sufficient.
A second important test is HPP processing of both HOM couplers. Quenching of coupler itself should not limit HPP processing, yet one must prove that both couplers can withstand this kind of the processing.

ACKNOWLEDGMENTS

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REFERENCES

[1] A.Mosnier, Working Group 5, Proceedings of LC92, Garmisch-Partenkirche, 1992.

[2] E.Haebel,A.Mosnier,J.Sekutowicz, "Cavity shape optimization for a superconducting linear collider", Proceedings of HEACC'92, Hamburg,1992

[3] Ph.Bernard,E.Chiavieri,E.Haebel,W.Weingarten,A.Mosnier, "Demountable E/H Higher Order Mode couplers for the niobium-sputtered 4-cell LEP cavity",Proceedings of the 5th Workshop on RF Superconductivity", Hamburg,1991.

[4] M.Fouaidy,T.Junquera,S.Chel,A.Mosnier,"Thermal Study of HOM Couplers for Superconducting RF Cavities", TESLA Report No. 93-25.

[5] J.Sekutowicz, "HOM Couplers at DESY", Proceedings of 3rd Workshop on RF Superconductivity, ANL Illinois, ANL-PHY-88-1/2,1987.

[6] H.Kaiser, private communication.

[7] S.Chel, M.Juillard, private communication.

[8] E.Haebel, private communication.