HIGHER ORDER MODE STUDY OF SUPERCONDUCTING CAVITY FOR ILC BASELINE

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Abstract

The development of superconducting cavities for ILC is under way at STF (Superconducting RF Test Facility)[1] in KEK. This paper summarize the higher order mode (HOM) study on KEK TESLA-shape 1.3GHz 9-cell superconducting cavities. The purpose of the study is aiming further optimization of TESLA-style HOM couplers, study of HOM field distribution and polarization characterization of major dipole modes for possible use as BPM. The improvement of TESLA-style HOM coupler by downsizing and the removement of 2nd stopband more carried out.

After checking by the Cu model, the Nb HOM couplers were made, and their filter characteristics were measured. Then the HOM couplers were welded to the 9-cell SC cavity, Qext of the fundamental mode and the each higher order mode of the couplers, each field distribution of HOM and polarization of dipole mode were measured by the network analyzer. After adjustment of notch frequency, the measurement of HOM coupler properties at 4 K was carried out during vertical dewar tests. The results are presented in this paper.

INTRODUCTION

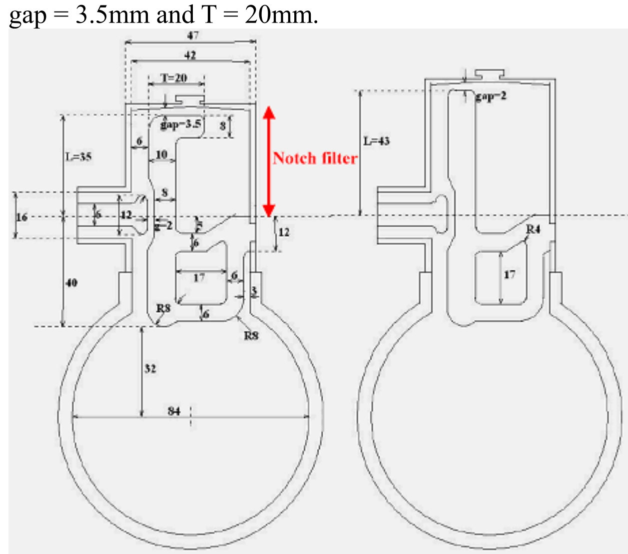
Four TESLA-shape cavities and four low loss cavities for installation into STF phase 1 cryomodule are under fabrication, and some of them are under vertical test[1]. Features of the KEK TESLA shape cavity are the followings [2]; Cavity end plates are increased their thickness more than TTF cavity to keep strength for Lorentz detuning during high gradient pulse operation. As a result, HOM coupler position is shifted away from cell end, coupling of HOM goes down. To improve HOM (also Input coupler) coupling, beam pipe diameter is extended from 78 mm to 84 mm. He jacket is designed by use of traditional TRISTAN SC cavity technology. The He jacket diameter requires more short HOM coupler in order to install jacket pipe from one side of beam pipe. We need short height HOM coupler than TESLA-style by more than 6 mm. In addition, result of measurement TESLA style HOM coupler model, we have confirmed exsistence of 2nd stopband at 4 GHz region. The improvement of this filter property is another purpose.

The purpose of this research is to design, manufacture and evaluate new HOM couplers for KEK TESLA-shape cavity.

HOM COUPLER DESIGN

Electrical Design

Our new design HOM coupler geometries are shown in Fig.1, where (a) is called as KEK L-type, and (b) is called as KEK I-type. Principle of the coaxial HOM coupler is in the following; The HOM coupler consists of a central conductor that forms the antenna and an inductive stub. The capacitor of conductor tip and the inductance of conductor that extends to the upper stub (length L) determine the center frequency of the band elimination filter corresponding to the fundamental accelerating mode (pi-mode) of the SC RF cavities at 1.3 GHz. The coupler is tuned to the band elimination frequency (notch frequency) by changing the gap of conductor tip. The HOM output coupling port serves as a conduit for the HOM power to the external load at room temperature. Note that effect of pick-up probe geometry and antenna gap also give the change of notch frequency (~few MHz). To obtain short coupler, length L must be short (inductance decrease). In this case, we must increase capacitance of conductor tip to tune the notch frequency. Increase of capacitor is done by increase in the area of conductor tip. The Gap of the tip is optimized to keep the sensitivity of frequency tuning (<50MHz/mm). In addition, welding point of inner and outer conductor converged on one point, in order to making welding point lower from the beam axis as much as possible. The geometry of the I-type filter is L =43 mm, gap =2 mm and T = 10mm. The geometry of the L-type filter is L = 35mm, gap = 3.5mm and T = 20mm.



(a) KEK L-type (b) KEK I-type

Figure 1: Design of HOM couplers.

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The HOM pick-up probe is a circular cylinder type (the diameter is 12mm), and the probe gap is 2 mm.

HFSS ver9.1 is used for the calculation of the filter characteristic. The calculation models are shown in Fig.2. The HOM coupler is put on the coaxial line. The filter property is evaluated by a transmission from TEM wave at the beam pipe to pick-up of the coupling loop antenna.

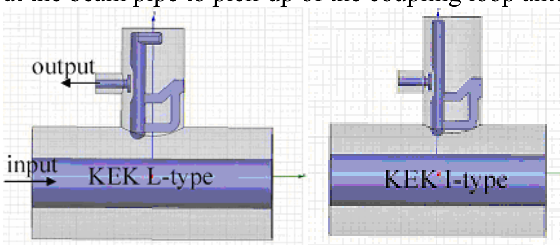


Figure 2: Calculation model by HFSS.

Transmission Measurement

A copper model and niobium couplers were made by using the calculation result, and the measurement was performed by a coaxial line test setup. Pictures of the niobium and copper antenna are shown in Fig.3.

Results of the calculation and the measurement are shown in Fig. 4. I-type (fig.4 (a)) has 2nd stopband at 4.1GHz. L-type (fig.4 (b)) has 2nd stopband at 4.5GHz. They have different 2nd stopband frequency respectively. Therefore a combination of I-type and L-type can be made each stopband reduced.

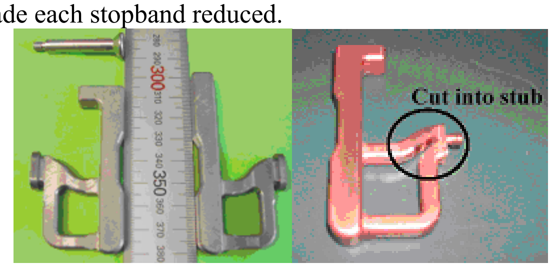
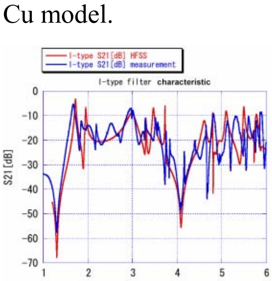
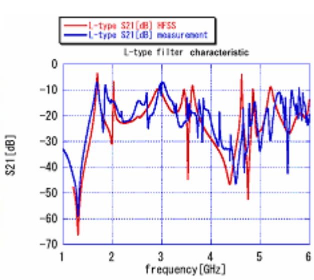


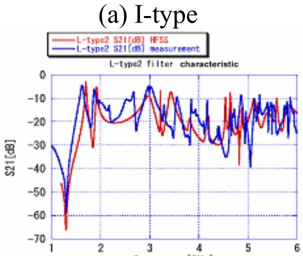
Figure 3: Pictures of the Nb and the Cu model of HOM couplers. (a) L, I-type and probe Nb model (b) L-type 2 Cu model.



(a) I-type



(b) L-type



(c)L-type 2

Figure 4: Comparison of the calculation and the measurement for filter properties.

The cut into the stub as shown in Fig.3 (b) was carried out. Result of improvement is shown in Fig.4 (c) named as "L-type 2". The L-type 2 could be effective to reduce the 2nd stopband, and to make the transmission property more flat.

Four Nb models of I-type and L-type were made respectively. The manufacture process is as follow: The antenna of models were manufactured by the wire cut method, the surface was removed by chemical polishing (CP: 30 to 50um), and then welded to the beam pipe. The change of the notch frequency at before/after CP is shown in the Table 1. After CP, the notch frequency was shifted 10~18MHz to the higher side. The electric polishing (EP1: 100um + EP2: 50um) was followed for whole 9-cell cavity including the HOM couplers. Cavity pre-tuning and HOM coupler tuning were done after EP1. After EP2, notch frequency was expected to shift higher side to <10MHz. Table 1: Notch frequency change by surface treatment.

Table 1: Notch frequency change by surface treatment

KEK I-type

No	Before surface treatment	After CP
1	1.317 GHz	-
2	1.291 GHz	1.305 GHz
3	1.299 GHz	1.309 GHz
4	1.307 GHz	1.321 GHz

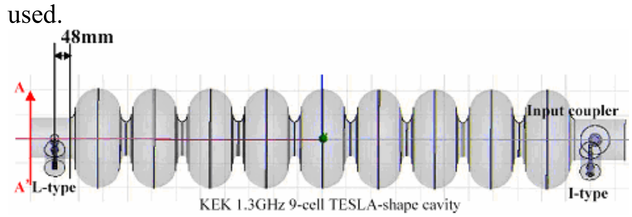
KEK L-type

No	Before surface treatment	After CP
1	1.320 GHz	-
2	1.273 GHz	1.291 GHz
3	1.259 GHz	1.267 GHz
4	1.274 GHz	1.286 GHz

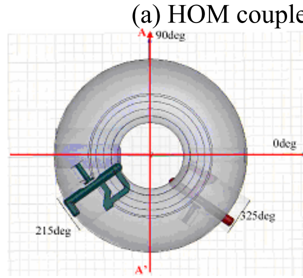
※CP:chemical polishing = 30 to 50um

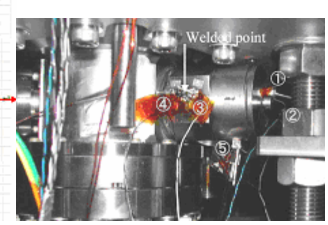
HOM MEASUREMENT OF CAVITY

Location of the HOM coupler position is shown in Fig. 5(a), (b). The cavity is equipped with an I-type and an L-type HOM coupler. Both HOM couplers loop is away at 48 mm from the cell-end. The loop tip was 32mm on the beam axis. Couplers angle are perpendicularly that seen from the beam axis. The L-type coupler is rotation of 215 deg around the beam axis. The I-type coupler is rotation of 325 deg around the beam axis. The angle between two HOM couplers are 110 deg. The field flatness of the fundamental mode was >98%. HOM was measured with the network analyzer. Ports of two HOM couplers were used.



(a) HOM coupler position





(b) Angle of HOM couplers (c) Temp. sensor

Figure 5: HOM coupler position in the 9-cell cavity.

HOM Passbands and Qext Measurements

Measurements of HOM passbands and Qext were done at 4 K. Measured modes were TE111, TM110 and TM011. Used pick-up probe (antenna gap = 2mm) is shown Fig.1. Passband frequencies of HOM are shown in Table 2. Dispersion of the frequency in each cavity is few MHz. Measured value of Qext were $3{\cdot}10^3$ ~$3{\cdot}10^5$ in TE111, $1{\cdot}10^4$ ~$1{\cdot}10^6$ in TM110 and $5{\cdot}10^5$ ~$5{\cdot}10^6$ in TM011.

Table 2: HOM passbands in the KEK TESLA-shape cavity

mode	Frequency[GHz]	mode	Frequency[GHz]	mode	Frequency[GHz]
TE111-1 R/Q=22.4	1.5956 1.5963	TM110-1 R/Q=119	1.7971 1.7981	TM011-1 R/Q=0.33	2.3186
TE111-2 R/Q=23.6	1.5977 1.5981	TM110-2 R/Q=89.1	1.8260 1.8266	TM011-2 R/Q=0.11	2.3213
TE111-3 R/Q=43	1.6091 1.6100	TM110-3 R/Q=52	1.8469 1.8474	TM011-3 R/Q=3.31	2.3292
TE111-4 R/Q=58.7	1.6276 1.6283	TM110-4 R/Q=864	1.8627 1.8631	TM011-4 R/Q=0.84	2.3383
TE111-5 R/Q=46.1	1.6501 1.6508	TM110-5 R/Q=1270	1.8750 1.8754	TM011-5 R/Q=8.65	2.3516
TE111-6 R/Q=549	1.6774 1.6780	TM110-6 R/Q=394	1.8845 1.8847	TM011-6 R/Q=6.26	2.3642
TE111-7 R/Q=2100	1.7063 1.7112	TM110-7 R/Q=0.28	1.8898 1.8899	TM011-7 R/Q=37.8	2.3801
TE111-8 R/Q=793	1.7410 1.7422	TM110-8 R/Q=20	1.8946 1.8948	TM011-8 R/Q=188	2.3906
TE111-9 R/Q=43.2	1.7723 1.7733	TM110-9 R/Q=0.005	1.8966 1.8968	TM011-9 R/Q=96.8	2.3998

Dipole Mode Polarization Measurements

Asymmetry come from process of manufacture and asymmetric position of each coupler will cause polarization in HOM. The purpose of polarization measurement is to identify the reason. Bead-pull method was used. The used bead is a machinable ceramic ball (diameter = 6 mm), which is sensitive to electric field only. The bead passed through a distance 30 mm (along iris) from beam axis. The measurement angle is 90 deg to 270 deg in the coordinate shown in Fig.5 (b). The polarize direction were determined from the maximum Δf in the iris cross section. The measurement modes were TE111 and TM110. Spectrums of dipole mode were a doublet structure due to asymmetry of the structure. But in case of the dipole mode strongly coupled with HOM couplers, the spectrum became to a single peak. The result of polarization measurement is shown in Table 3. The difference of the polarization direction was within less than in each cell 10 deg.

Table 3: Polarized direction (The direction is defined in Fig.5 (b).)

measured mode	polarize direction		other
	Low peak	High peak	
TE111-1,-2	330 deg	60 deg	Seem to doublet
TE111-5,-6,-7	5 deg	95deg	Seem to 1 peak :very strong coupling
TM110-1,-2,-3,-4,-5,-6	310 deg	40 deg	Seem to doublet

Vertical Tests

For actual operation, HOM couplers were loaded the fundamental RF field in a cavity. The ratio of the loaded field to equator and HOM coupler is about 0.045. The input RF power in vertical tests was operated in CW. The problem of heating in HOM pick-up probe and inner conductor was identified in J-lab [4], [5]. Heating at the probe of the I-type and the L-type HOM coupler (probe condition is Fig.1) occurs at more the 14 MV/m. As a countermeasure, the probe gap was extended from 2 mm to 6 mm, and the probe diameter changed from 12 mm to 6 mm. The temperature sensors of carbon resisters, power meter for fundamental power leakage and x-ray radiation monitors were O.K. In the all temperature sensors were set as shown in Fig.5(c). They were put on the coupler tip and the welded point at the inner conductor. Radiation monitor was put the outside of cryostat. Trip power levels of both HOM couplers were 3, 5, 8, 10, 12, 13, 16 MV/m. When a trip occurred, a spike response with ms the time constant of ~500 were observed. X-ray signal was synchronized with temperature signals. After processed of these trips, HOM couplers became stable until the cavity quench reached (the quench level was 20.3MV/m in this test).

SUMMARY

The new HOM couplers for KEK TESLA shape cavity are designed and evaluated. The 2nd stopband were observed in these HOM couplers. The flat transmission property was achieved with the L-type 2 coupler. The measured Qext of major HOM were one order bigger than the value of the TTF design. As a countermeasure, narrowing the gap of probe, and extend of the probe tip area should be considered. To improve TM011 coupling, the loop angle will be changed in the next model. Polarization direction was roughly the same cell in the direction in each cell. Polarization direction of the input coupler side cell, however, differed slightly from another cells. The I-type and the L-type HOM couplers were stably operated until 20.3 MV/m in this 9-cell cavity.

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