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DEVELOPMENT OF HOM COUPLER WITH C-SHAPED WAVEGUIDE FOR ERL OPERATION

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Abstract

We are developing the higher-order mode (HOM) attenuators for superconducting cavity for high current beam operation. We propose new type of HOM coupler using C-shaped wave guide (CSWG). The CSWG has good features of high-pass filter, easy cooling of the inner conductor, and compactness. The measured and calculated results of the CSWG type HOM coupler installed to TESLA type cavity model showed good properties of high external Q-value for the accelerating mode and low external Q-values for HOMs. Since CSWG becomes long to get high external Q-value for accelerating mode, bending CSWG type HOM coupler is practical considering the cryomodule design. The bent CSWG type HOM coupler showed similar properties to the straight CSWG.

INTRODUCTION

The superconducting accelerator projects such as International Linear Collider (ILC) or Energy-Recovery Linac (ERL) are pushed forward all over the world. The superconducting cavity has an advantage of high Q-value due to few wall losses. This leads to a disadvantage that beam acceleration easily grows up higher-order modes (HOMs). Since HOMs excited in a cavity increase with beam current and cause beam instability [1], the performance of HOM attenuators finally limits cavity performance.

Desirable properties of the HOM attenuators so as not to deteriorate the cavity performance are as follows.

i. Ability to install near the cavity not to decrease the effective accelerating field.
ii. Effective cooling to avoid the temperature rise leading to breaking superconductivity for high power of HOMs.
iii. Separation of RF absorbers such as ceramics and ferrites from the cavity vacuum which might be sources of outgas and dust.
iv. Compactness to reduce the cryomodule size.

We developed the C-shaped wave guide (CSWG) as shown in Figure 1 [2]. The CSWG has the cutoff frequency determined by an inner diameter, an outer diameter, and a connection plate thickness since the CSWG is topologically similar to the rectangle wave guide. Furthermore, since the inner conductor connected with the outer conductor through the connection plate, the CSWG has an advantage of easy cooling of the inner conductor. Applying the CSWG to the HOM coupler satisfies the above requests.

The present paper describes the measured and calculated results of the CSWG type HOM coupler properties.

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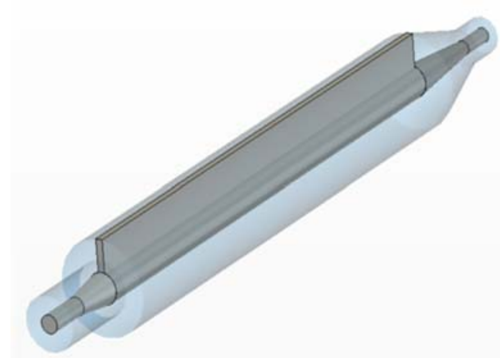

Figure 1: Schematic view of CSWG connected with coaxial lines at both ends.

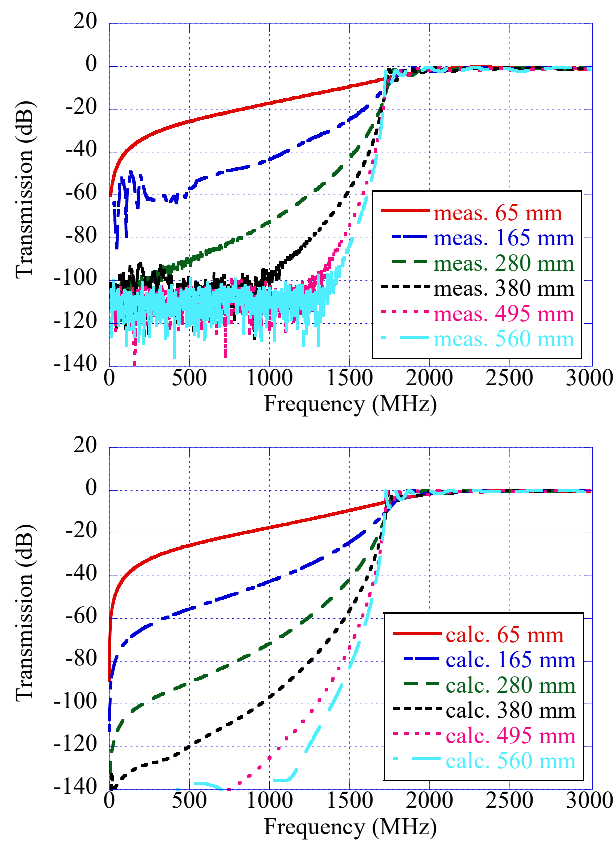

Figure 2: Measured (top) and calculated (bottom) transmission coefficients through CSWG for different CSWG length.

CSWG MODEL

The aluminium CSWG models were fabricated to measure the RF properties. The inner and outer diameters were 18 mm and 42 mm, respectively. The CSWG length can be varied from 65 mm to 560 mm. The coaxial-N

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type connector converters were attached to the both ends and transmission coefficients were measured with a network analyzer. The calculations were also done for the same shape as the models with CST Microwave Studio.

The transmission coefficients through the CSWG for different CSWG length and for different connection plate angles are shown in Figure 2 and 3, respectively When the CSWG length increases, the attenuation below cutoff frequency becomes large and the transmission above the cutoff frequency is almost same. When the angle of the connection plate increases, the cutoff frequency increases. Measurements well agree with calculations in both cases.

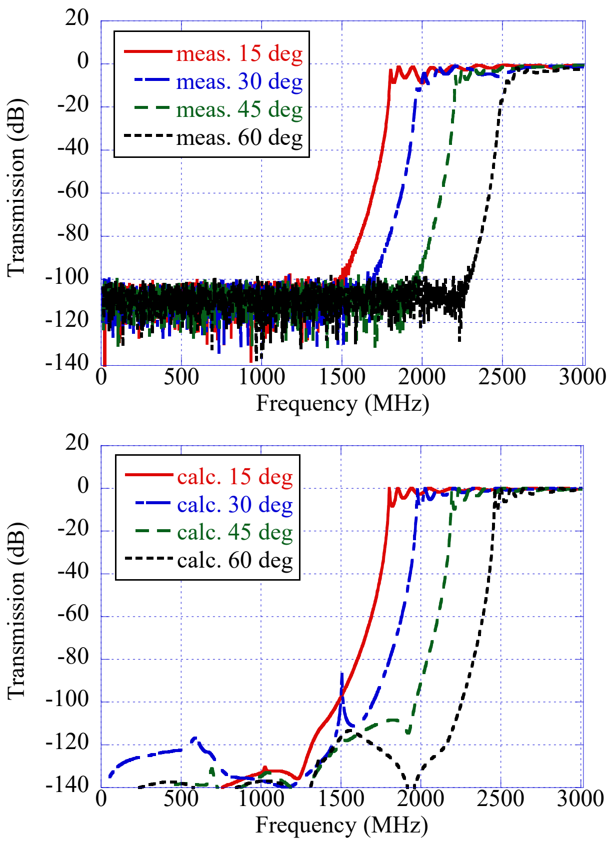

Figure 3: Measured (top) and calculated (bottom) transmission coefficients through CSWG for different connection plate angle.

CSWG TYPE HOM COUPLER

The schematic view of the CSWG type HOM coupler is shown in Figure 4. The CSWG type HOM coupler can be divided into three roles. The first is the coaxial line extended from the CSWG to couple with the cavity RF. The second is the CSWG through which the HOMs above the cutoff frequency transmit and the fundamental mode below the cutoff frequency is reflected. The third is the coaxial line to extract the HOM power outside of the HOM coupler.

The aluminium CSWG type HOM coupler model was fabricated to measure the RF properties. The inner diameters of CSWG type HOM coupler were 18, 21, 25.8 and 30 mm, the outer diameter was 42 mm, and the thickness of connection plate was 4 mm for all types of the inner diameters. The CSWG length can be varied from 65 mm to 560 mm. The CSWG length is defined as the center line length of the inner conductor connected with the connection plate. The end of connection plate for cavity side was located 27 mm outside from the beam pipe. In order to couple with the cavity RF a cylindrical rod was connected to the inner conductor of CSWG. The insertion length is defined as the length from the beam pipe to the tip of the coaxial line. The positive value means the tip is inside of the beam pipe.

The CSWG type HOM coupler was installed to the TESLA type cavity model. The TESLA cavity is designed to install the antenna type HOM couplers. The HOM coupler port is located 40 mm away from the cell end at the beam pipe. Though installing HOM couplers near the cavity does not require extra beam pipe which decreases the effective accelerating field, the high-pass filter structure is essential so as not to affect the accelerating mode. The CSWG type HOM coupler can be replaced with antenna type HOM couplers owing to the cutoff frequency of the CSWG.

The cavity model has three cells to reduce the number of HOMs to be measured and calculated as shown in Figure 4. The TESLA type cavity model is made of copper. The diameter of the beam pipe was 78 mm. The input port for measurement was installed at the end cell. The RF connectors of the input coupler and the CSWG type HOM coupler were connected to the network analyzer to measure the RF transmission and reflection coefficients.

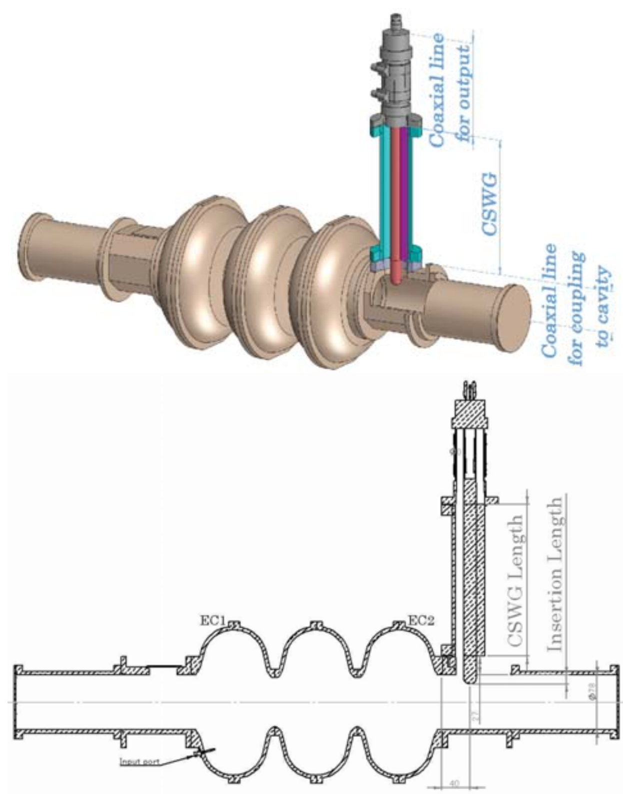

Figure 4: Schematic view (top) and cross section (bottom) of CSWG type HOM coupler installed to the TESLA type cavity model.

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RESULTS

The external Q-values of the CSWG type HOM coupler were measured and calculated by changing the CSWG length and the insertion length. The measured and calculated external Q-values for the accelerating mode are shown in Figure 5 as a function of the CSWG length. Increasing the external Q-values for accelerating mode with the CSWG length means that the accelerating mode below the cutoff frequency could not transmit through the CSWG. On the contrary the external Q-values of the HOMs above the cutoff frequency were almost same regardless to the CSWG length as shown in Figure 6. These mean that the HOMs could transmit through the CSWG to be damped.

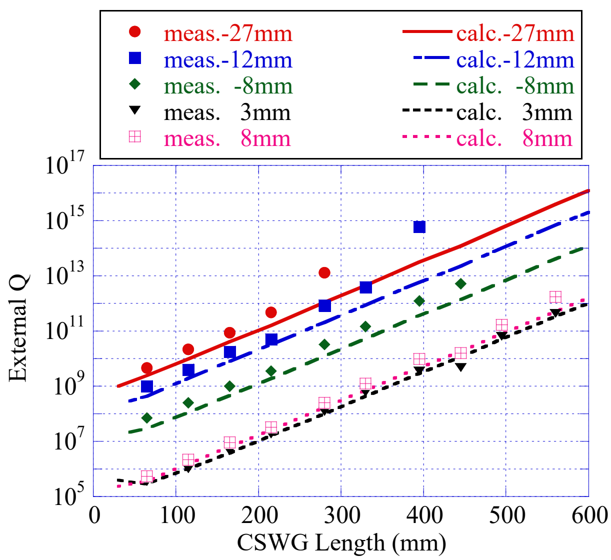

Figure 5: Measured and calculated external Q-values of the accelerating mode as a function of CSWG length for different insertion length.

The CSWG length increases the external Q-value for the accelerating mode and is independent of that of HOM. The insertion length decreases the external Q-values for the accelerating mode and HOMs. When the parameters of CSWG type HOM coupler are decided, first select insertion length for external Q-values of HOMs to be small enough, and then select CSWG length for external Q-values of accelerating mode to be large enough.

The TESLA cavity has two different shapes of the end cells, endcap 1 (EC1) and endcap 2 (EC2), to enhance the field amplitude of the trapped mode in one end cell [3]. The distribution of the external Q-values with the CSWG type HOM coupler installed at either EC1 or EC2 side is shown in Figure 7. Since the asymmetric end cell shapes enhances HOM amplitude to either side of the end cell, some degraded HOMs show high Q-values. The HOM coupler installed at either EC1 side or EC2 side can lower the external Q-values less than 10^6 at least, while the external Q-values for the accelerating mode can be kept more than 10^{11}.

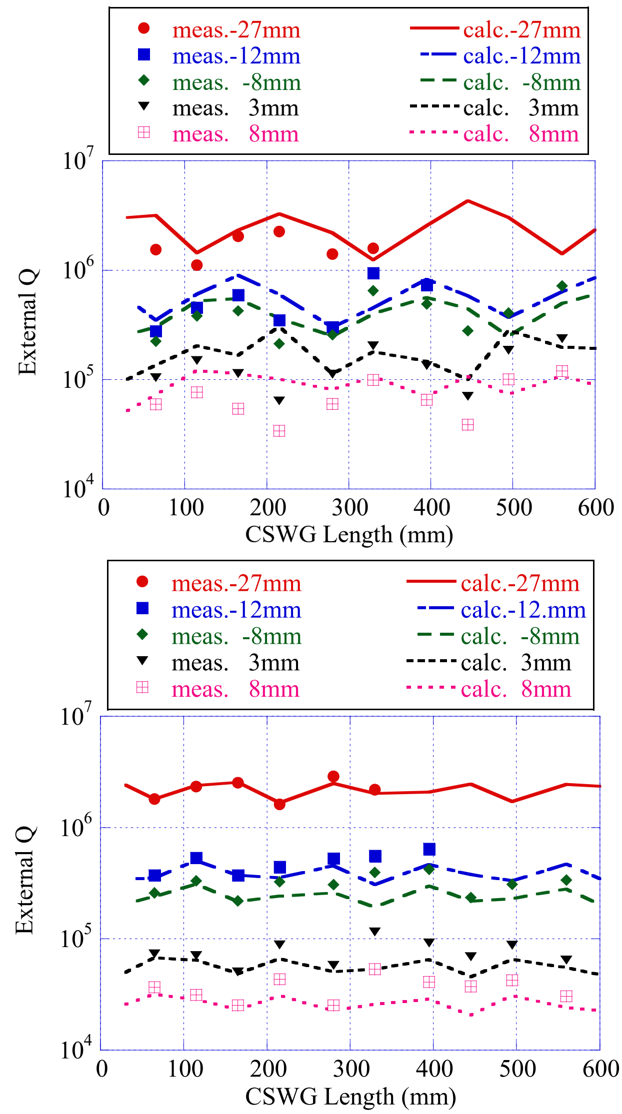

Figure 6: Measured and calculated external Q-values of TE111-pi/3 mode (top) and TM110-pi mode (bottom) as a function of CSWG length for different insertion length.

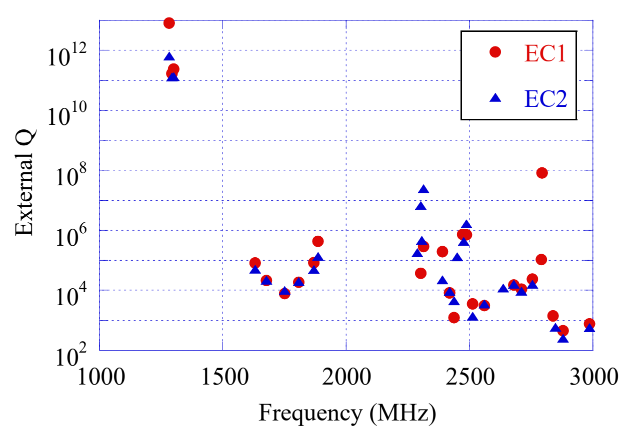

Figure 7: The distribution of measured external Q-values for CSWG HOM coupler of either EC1 or EC2 side.

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BENDING CSWG TYPE HOM COUPLER

The CSWG type HOM coupler requires a long pipe so as not to affect the accelerating mode when it is installed near the cavity. Since no bending of the CSWG type HOM coupler requires large radial size of a cryomodule, the bent CSWG type HOM coupler is practical as shown in Figure 8. The effects to the RF properties for bending the CSWG type HOM coupler were investigated. The CSWG type HOM coupler was bent at 90 degrees to be parallel to the beam axis with a quarter regular polygon. The bending angle is defined as the exterior angle of the regular polygon. The direction of the connection plate is defined as "inside" when it is located in the inside of the bending section.

Figure 9 shows the measured external Q-values with CSWG type HOM coupler of bending angle of 45 degrees for three directions of connection plate. Outside connection plate direction is preferable for the accelerating mode because of higher external Q-value. According to the HOMs, suitable connection plate directions vary, but the differences are little.

Figure 8: Bent CSWG HOM coupler of bending angle of 45 degrees installed to TESLA type cavity model.

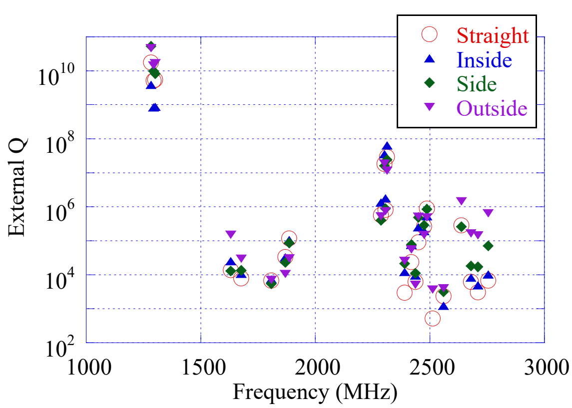

Figure 9: Measured external Q-values with bent CSWG type HOM coupler of bending angle of 45 degrees with three directions of connection plate.

CONCLUSION

The CSWG has good features for HOM attenuator such as high-pass filter, easy cooling of inner conductor, easy conversion to coaxial-line, and compactness. With these features the CSWG type HOM coupler realizes good attenuation properties of high external Q-value for accelerating mode and low external Q-values for HOMs.

Bending the CSWG type HOM coupler is practical for considering the cryomodule design. The external Q-values are almost same as those of straight CSWG regardless of bending angle except for the 90-degree bending of the inside connecting plate.

The structure of bent CSWG type HOM coupler is complicated and fabrication process is under investigation

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